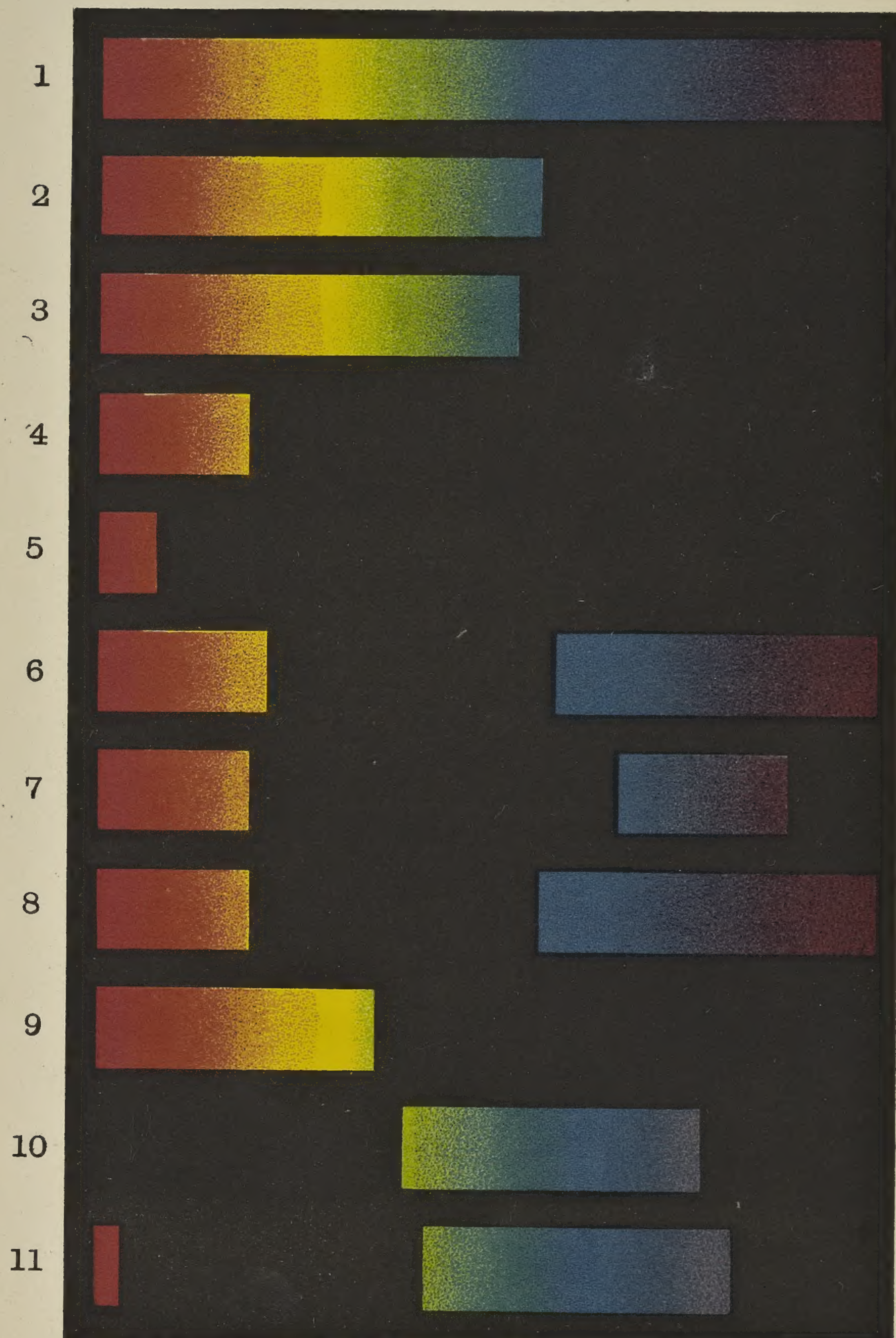
COLOUR

GEORGE H. HURST


So very, very
true, and so
very, very
pretty.
Just as
pictured.

3 —

PLATE I.



COLOUR

A HANDBOOK OF THE THEORY OF COLOUR

BY

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WITH TEN COLOURED PLATES AND SEVENTY-TWO ILLUSTRATIONS

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PREFACE.

The subject of colour is always one of considerable interest, more especially to those who, like artists, painters, dyers and calico printers, use colour or colours in their everyday work. Such persons will have considerable practical experience in the mixing and application of colours for various purposes—painting, dyeing and printing of textile fabrics, etc.; and they will have met with, from time to time, some curious effects of mixing various colours together. To such persons a knowledge of theory of colour, its cause and production, and a succinct account of the phenomena which occur on mixing colours together in various ways, will be of interest. In the following pages an endeavour has been made to present such matters in as clear a form as possible, and, having in mind the latest investigations in the field of colour, particular regard has been paid to the requirements of the practical man, and attention given to the explanation of the effects which are

obtained by mixing various dyes and pigments together, as is done every day by the dyer and painter.

In writing this book the author has obtained some help on the subject from the manuals of Chevreul, Benson, Rood, Church, and others, and to such he now begs to pay his acknowledgments.

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22 BLACKFRIARS STREET,
SALFORD, *June*, 1899.

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COLOUR.

CHAPTER I.

COLOUR AND ITS PRODUCTION.

Light.—Some bodies, such as the sun, gas flame, candle flame, electric lamp, etc., emit their own light; these are known as self-luminous bodies, and we see them in virtue of the light they emit. Other bodies, comprising the great majority of those known to us, do not emit light, and are therefore non-luminous. Such bodies are rendered visible by reflecting the light which falls upon them from luminous bodies. That this is so is a fact which is demonstrated every day when the sun going down causes objects to become invisible; while in tunnels, where absolute darkness reigns, no object is at all visible.

Colour.—It is also to the light which falls upon them that bodies owe their colour. Go into a flower-garden at mid-day, and the flowers show many and variegated tints, from the faintest tint on the blush rose to the darkest and most deeply coloured dahlia that is grown—pinks, reds, yellows, violets and blues, to say nothing of the variegated shades of green of the foliage. Go into the same garden at night: all the colours will have vanished, and foliage and flowers will have the same hue of blackness. Colour, therefore, is dependent on light. The same inference can be

drawn from the difference in appearance of a room at night, before and after the light is put out.

Dispersion of White Light.—But how does light affect the production of colour ? The answer is to be found in the classical experiments of Sir Isaac Newton. Let the shutters of a window be tightly closed at mid-day, so that no light can enter. Make a hole in the shutter ; the light streaming in will cross the room and appear as a bright spot on the opposite wall. Possibly the path of the light will be rendered visible as a beam or a ray by its action on the dust particles which are always to be found floating in the air. If now a triangular glass prism be placed in the path of the sunbeam, so that the beam passes through one edge, a change in both its direction and character will be noticed ; instead of continuing in a straight line, it will be bent out of its course to a considerable extent, and will now appear, at a greater or less distance laterally from its former position, not as a bright spot of white light, but as a band of variously coloured lights of the same character and order as the colours in the rainbow, which, as a matter of fact, owes its existence to the same kind of action. This band of coloured light is called the *spectrum*, and the colours are known as spectral or *spectrum colours.*

This dispersion of white light by its passage through a prism is illustrated in Fig. 1, which represents the path of white light through one edge of a triangular prism A, which is the form commonly used in carrying out such experiments, but any other form will give similar results. The lines *aa* represent a ray of white light ; if there were no prism it would strike the screen S at *b* ; but the ray of light passing into the prism at *c* is refracted in the direction *cd* ; while passing out at *d* it is again refracted and proceeds in the direction *df* ; the light is now rendered divergent and therefore forms a band, *ef*, on the screen, S, not of white light, but of various colours,

as shown in Plate 1. For convenience of reference Sir Isaac Newton divided the spectrum into seven parts—red, orange, yellow, green, blue, indigo and violet—which are popularly spoken of as the seven colours of the spectrum or rainbow ; but it will be seen hereafter that this division into seven colours is a purely arbitrary one. The spectrum of white light is shown on Plate 1, No. 1.

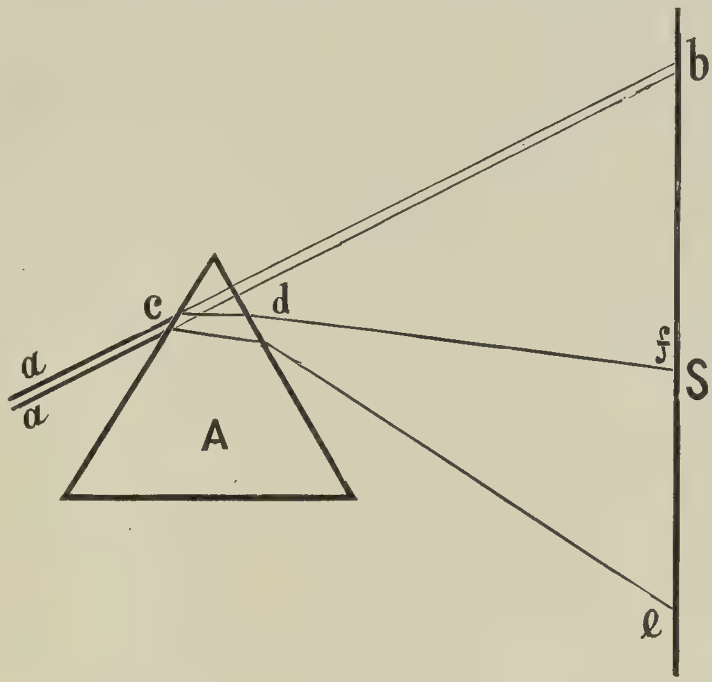


FIG. 1.

METHODS OF PRODUCING THE SPECTRUM.

There are several ways of producing colour from white light :—

(1) By means of a glass prism ;
(2) By means of a diffraction grating ;
(3) By means of the polariscope ;
(4) By means of phosphorescent and fluorescent bodies ;
(5) By means of thin films ;
(6) By the action of coloured bodies.

I. BY MEANS OF A GLASS PRISM. Names of Colours.— When, as stated above, a beam of white light is passed through a prism, as shown in Fig. 1, it is dispersed and a band of coloured light produced, the spectrum, Plate 1,

having at one end red, at the other end violet. Newton, who first discovered this property of the prism, divided the spectrum into seven divisions, *viz.*, red, orange, yellow, green, blue, indigo and violet. In naming them, however, it is much better to follow the nomenclature of Rood, and to call the principal colours red, orange-red, orange, orange-yellow, yellow, green, cyan blue, blue and violet. There is, however, no sharp line of demarcation between these colour divisions, the red passing insensibly into the orange-red, the orange-red into the orange; this into the yellow, the yellow imperceptibly into the green; this into the blue and the latter into the violet; so that, really, we have not simply seven colours in the spectrum, but an infinite number of colours, for all of which language fails to find names.

Fixed Lines of Spectrum.—Fraunhofer was the first to notice that the spectrum of sunlight was not a continuous one, but was broken by a large number of fine lines; Dr. Wollaston also made the same discovery. These lines, which are called the *fixed lines*, have an interest as forming standards by means of which the various portions of the spectrum may be located, for some of them are much more prominent than others and have received reference letters, starting from the red end of the spectrum; these are shown in Fig. 2, which is taken from Rood, who gives the following measurements of the various portions of the spectrum, on the assumption that the distance from A to H is divided into 1000 parts.

Fixed Lines of the Solar Spectrum.—The fixed lines of the spectrum shown in the figure fall at the following places:—

A . . .	0	E . . .	363·11
a . . .	40·05	b . . .	389·85
B . . .	74·02	F . . .	493·22
C . . .	112·71	G . . .	753.58
D . . .	220·31	H . . .	1000

Coloured Spaces of the Prismatic Spectrum.—The following table shows the positions occupied by the various colours

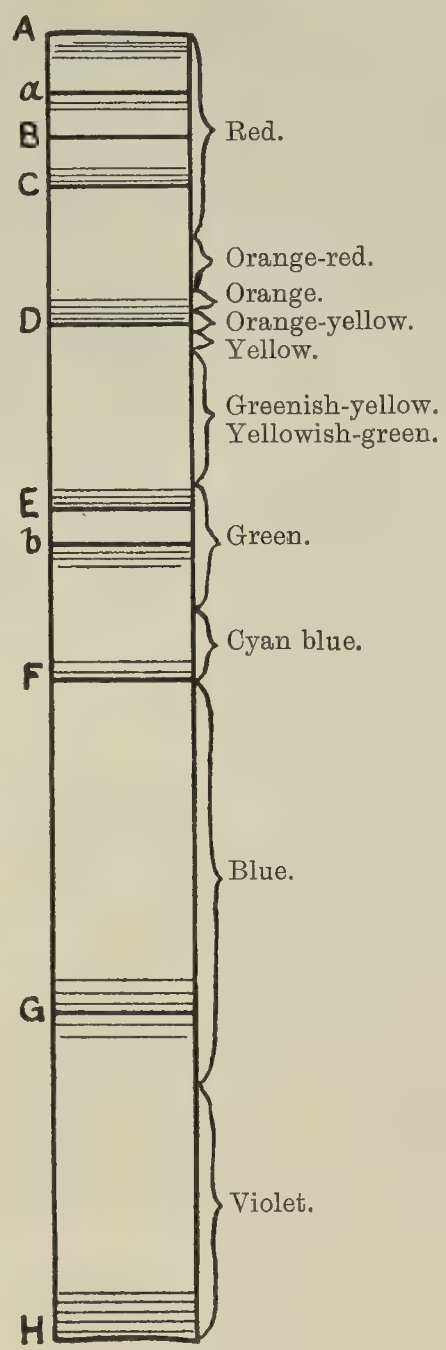


Fig. 2.

as measured by Rood, which correspond closely with observations made by the author:—

	Extends from
Red	0 to 149
Orange-red	149 ,, 194
Orange	194 ,, 210
Orange-yellow	210 ,, 230
Yellow	230 ,, 240
Greenish-yellow	240 ,, 344
Green	344 ,, 447
Cyan blue	447 ,, 495
Blue	495 ,, 806
Violet	806 ,, 1000

Relative Space of the Spectrum Colours.—From these measurements the following table has been constructed, which shows the space occupied by each division or colour :—

Red	149
Orange-red	45
Orange	16
Orange-yellow	20
Yellow	10
Greenish-yellow and yellowish-green	104
Green and blue-green	103
Cyan blue	48
Blue and blue-violet	311
Violet	194

The two foregoing tables, however, do not give the full length of the spectrum, as in front of A there is a dark-red portion which gradually shades off into blackness; while at the other end beyond H there is a faint greyish kind of tint which has been called lavender. It may be added that in making such observations it is necessary that each portion of the spectrum be isolated from the rest, a matter which is very easily done, so that the effect of contrast (see Chapter III.) on the hues may be eliminated, and, further, it is desirable that the source of light be as bright as possible.

The order of the colours in the spectrum is that of the wave lengths as shown below. It might be assumed that in a normal spectrum the position of each colour would be in proportion to the wave length, but we find that in the spectrum produced by a glass prism such is not the case;

thus in some portions there is undue crowding, while in others the space occupied by the colours is unduly extended; this is the case with the blue and violet end, notably the latter; while the red, orange and yellow, particularly the two latter, are much shortened.

Wave Motion of Light.—Several theories have been devised from time to time for the explanation of all the phenomena of light—that known as the undulatory theory being the one which most physicists have hitherto accepted as most in accordance with the facts. This presupposes that all space and the bodies in it are permeated by an exceedingly light or even intangible entity known as the ether, and that light is propagated through this by vibrations or undulations or waves, just as waves in water are propagated and as sound waves in air are formed. In all cases of wave motion there is, practically, no transference of matter, etc., from the source of the movement onwards, but simply a short to-and-fro undulation, which is imparted from particle to particle of the medium in which the wave motion is travelling; in this way effects are transmitted to considerable distances from the exciting cause. The sun, or other source of light, sets up these vibratory movements in the ether, which ultimately reaches the retina of the eye and gives rise to the sensation of light.

In waves we recognise two elements—wave length and amplitude. On the surface of a liquid such as water, the distance between the crests of two waves is known as the *wave length;* while the height from crest to trough is known as the *amplitude of the wave.* It has been shown that it is on the degree of the latter element that the intensity, or the power of doing work, of the wave depends; thus of two waves of the same wave length that which has the greatest amplitude is the most powerful, the power varying as the square of the amplitude.

In light, difference of wave length gives rise to difference

of colour ; thus the waves of red light are longer than those of violet light, while orange, yellow, green and blue light rays are intermediate in their wave lengths.

The Fraunhofer lines, being fixed and constant in position, have become standards for the measurement of the spectrum. They have been lettered, for ease of reference, from A in the red end of the spectrum to H in the violet end, and the wave lengths of the light at those portions of the spectrum have been measured and are given in the following table in units of $\frac{1}{10000000}$ of a millimetre.

Line.	Position in spectrum.	Wave length in ten-millionths of a millimetre.
A	Red	7594
B	Red	6867
C	Red-orange	6562
D	Orange-yellow	5892
E	Green	5269
F	Blue	4861
G	Violet	4307
H	Violet	3968

II. **BY MEANS OF A DIFFRACTION GRATING.**—The second of the means referred to above for decomposing white light, that of a diffraction grating, allows of a spectrum of normal length in proportion to the wave length of the colours being obtained. If the glass prism be replaced by a metal or glass plate ruled with a large number of fine lines, in some cases 20,000 to the inch, and the light be reflected from that, a spectrum is obtained which gives the various colours almost but not quite in their true position ; a diffraction spectrum is, however, much less intense than a prismatic spectrum.

Fixed Lines of the Normal Spectrum.—Measurements made by Rood of a normal spectrum produced in this way give the position of the fixed lines as follows :—

A	0	E	638.92
a	113.74	b	664.79
B	201.61	F	749.24
C	285.05	G	902.07
D	468.38	H	1000

Positions of Colours in Normal Spectrum.—The next table gives the positions of the colours in the normal spectrum according to Rood:—

	Extends from
Red	0 to 330
Orange-red	330 ,, 434
Orange	434 ,, 459
Orange-yellow	459 ,, 485
Yellow	485 ,, 498
Greenish-yellow	498 ,, 595
Full green	575 ,, 682
Blue-green	682 ,, 698
Cyan blue	698 ,, 823
Violet-blue	153 ,, 940
Violet	940 ,, 1000

Spaces occupied by the Colours in a Normal Spectrum.—The amount of space occupied by each colour in such a spectrum is shown in the following table:—

Pure red	330
Orange-red	104
Orange	25
Orange-yellow	26
Yellow	13
Greenish-yellow and yellow-green	97
Full green	87
Blue-green	16
Cyan blue	51
Blue	74
Violet-blue and blue-violet	117
Pure violet	60

If the white light can be so split up into these coloured lights, the question arises whether each of the spectrum colours may not be split up further by a second passage through another prism, as shown in Fig. 3. Here A represents a beam of white light passing through a prism P and hence dispersed, the rays falling on the screen B, an opening in which permits of the portion C passing through and falling on a second prism D where it undergoes further dispersion, falling ultimately on a second screen E at H. The second dispersed rays, however, are not altered in kind from the rays which fall on the second prism, being simply

widened out at H. Therefore each portion of the spectrum consists of one kind only of coloured light rays.

Spectroscope.—The instrument by means of which white light can be resolved into its constituent colours and by which other observations on colour can be made is known as the spectroscope. Such an instrument is shown in Fig.

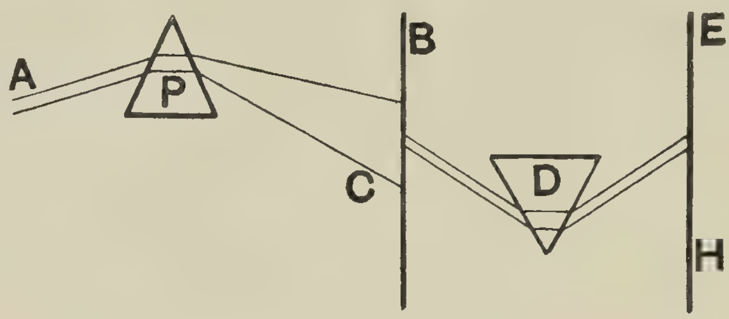


FIG. 3.

5. In its simplest form it consists of three parts. First, a tube which carries at one end a slit arrangement by means of which a narrow beam of light can be obtained, while at the other end is a lens, called a collimating lens, for the purpose of converting the diverging rays which pass through the slit into parallel rays. Second, a glass prism, through which the rays from the slit are passed; and, third,

FIG. 4.

a telescope G by means of which the spectrum produced may be observed.

Fig. 4 is an illustration of Browning's straight vision spectroscope, which is useful for making observations of the absorption spectra of coloured glass or coloured liquids, it being only needful to hold the glass or a drop of the liquid against the end of the apparatus, and direct the instrument to the sky, when the spectra will be observed.

In the majority of instruments only one prism is used, but if a wider dispersion of the rays is required then more may be added, and spectroscopes with six prisms have been made. In some instruments there is also an arrangement by means of which a graduated scale can be produced in the field of view of the telescope so that measurements of the spectrum can be made. In some instruments arrangements are made whereby two spectra can be produced side by side for the purpose of comparison.

A diffraction spectroscope is similarly constructed, but the prism is replaced by a diffraction grating, the light passing

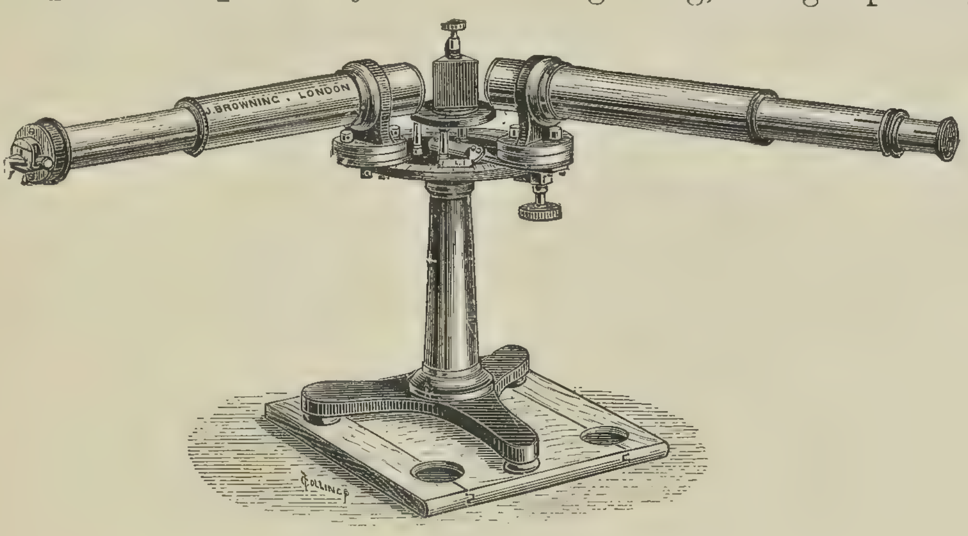


FIG. 5.

through the slit and collimating lens being reflected into the telescope from the grating (see page 6).

Recomposition of White Light.—As white light can be split up into many coloured lights, so by combining coloured lights together white light can be reproduced; this can be effected in several ways. One method is shown in Fig. 6, in which the dispersed beam produced by the prism A is received on a concave mirror B and reflected to a point D, where the various coloured rays have all converged and again form white light. In place of using a single concave mirror, the various portions of the spectrum produced by the prism may

be received on a series of mirrors and reflected to one spot where white light will again be formed.

Another plan, which has been found very useful in the construction of lenses for microscopes and other optical instruments, is to pass the rays from the dispersing prism through a second one placed in the reverse position, as shown in Fig. 7, in which the path of the rays of light through the two prisms is traced. It may be pointed out here that the degree of dispersion varies with different kinds of glass—a

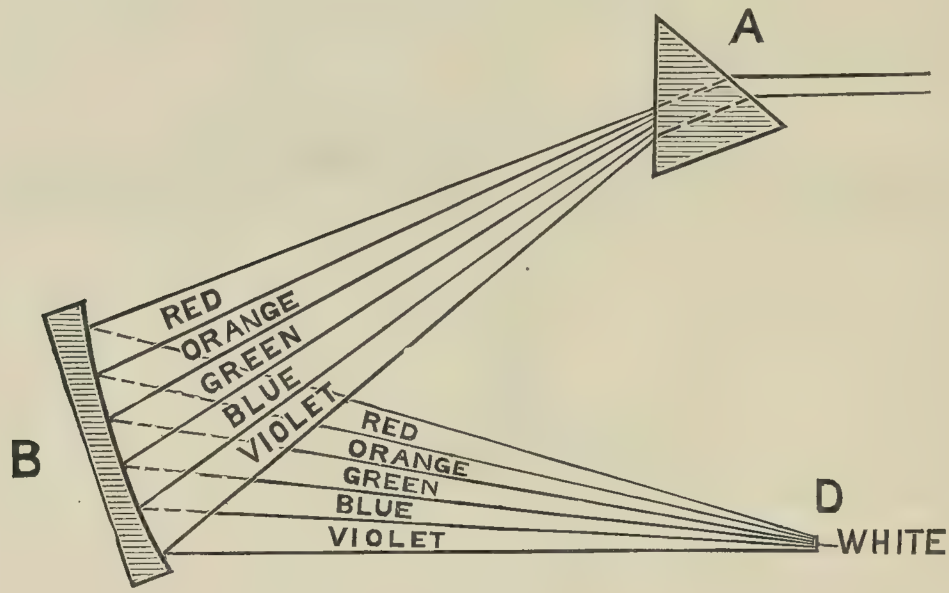


FIG. 6.

prism made of flint glass will disperse the light much more than a similar prism made of crown glass. The passage of light through lenses is always accompanied with a certain amount of dispersion, which interferes with the definition of objects by surrounding them with a fringe of coloured light, this phenomenon being known as "chromatic aberration." It can be remedied by making the lens a compound one, a convex lens of crown glass with a meniscus or plano-concave lens of flint glass, the latter by its greater dispersive power destroying the chromatic aberration of the crown glass

lens, while the compound lens acts like a convex lens on the light rays which pass through it.

Another, but not so perfect a method, is to paint a white card disc in radial divisions in the seven principal colours of the spectrum, as at 1 in Plate 2. If this be made to rotate by means of the revolving arrangement shown in Fig. 44, then, by the operation of persistence of vision, which will be more fully dealt with in another chapter, the various colours appear to blend one into the other, and a more or less greyish-white appears. A pure white can never be obtained, on account of the fact that the pigments used in painting the disc are not pure in colour, as will be noticed later on.

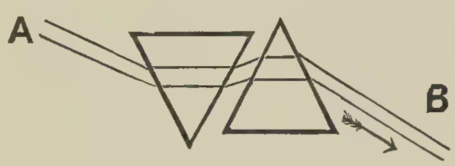


FIG. 7.

Hue.—There are three constants, as they are called, which accompany every colour ; these are hue, luminosity and purity. The *hue* of a colour is that constant which is commonly denominated by the term colour, as blue, or green, or red, or yellow, or rose, or violet, all which terms are employed to distinguish certain colour sensations one from the other. The only true standard for hue is the spectrum, and we may measure the hue of any particular colour by noting the position in the spectrum it occupies or by determining the wave length of the colour rays. The following table gives the position in a normal spectrum, with the corresponding wave length of the coloured light reflected from discs painted with various pigments to imitate spectrum colours :—

Name of the colour.	Position in the normal spectrum.	Wave length in ten-millionths of a millimetre.
Vermilion	387	6290
Red lead	422	2061
Chrome yellow	488	5820
Emerald green	648	5234
Prussian blue	740	4899
Cobalt blue	770	4790
Ultramarine (natural)	785	4735
Ultramarine (artificial)	857	4472
Same tinted with Hoffman's Violet BB.	916	4257

Very minute differences in the hue of colours are distinguishable by the eye, but are almost indescribable by language. Aubert, many years ago, made some experiments on the sensitiveness of the eye to changes of colour by means of coloured discs. It was found that the addition of one part of white light to 360 parts of coloured light brought about a change which was perceptible, and changes amounting to only $\frac{1}{100}$ to $\frac{1}{300}$ part of colour are readily perceptible. Aubert states that more than a thousand hues are distinguishable in the spectrum, and it is possible to recognise even small variations of these hues. The addition of one part of Chinese blue to 400 parts of barytes is sufficient to impart a very perceptible blue tint to the latter, while the addition of an equal quantity of chrome yellow will cause a change in the hue of the mixture, making it become more greenish. Mr. Charles Pierce has made experiments on this subject, and has found that the power of perception of the eye is the same for all the spectral colours.

Luminosity.—The second constant of light is *luminosity* or *brightness*. A sheet of yellow paper appears to the eye to be much brighter or more luminous than a sheet of red paper, or a sheet of blue paper. The most luminous surface is a white one; the least luminous, a black one; and between these two there is every degree of luminosity. It is possible to measure the relative luminosity of the spectrum colours, by isolating each one and ascertaining the relative amount

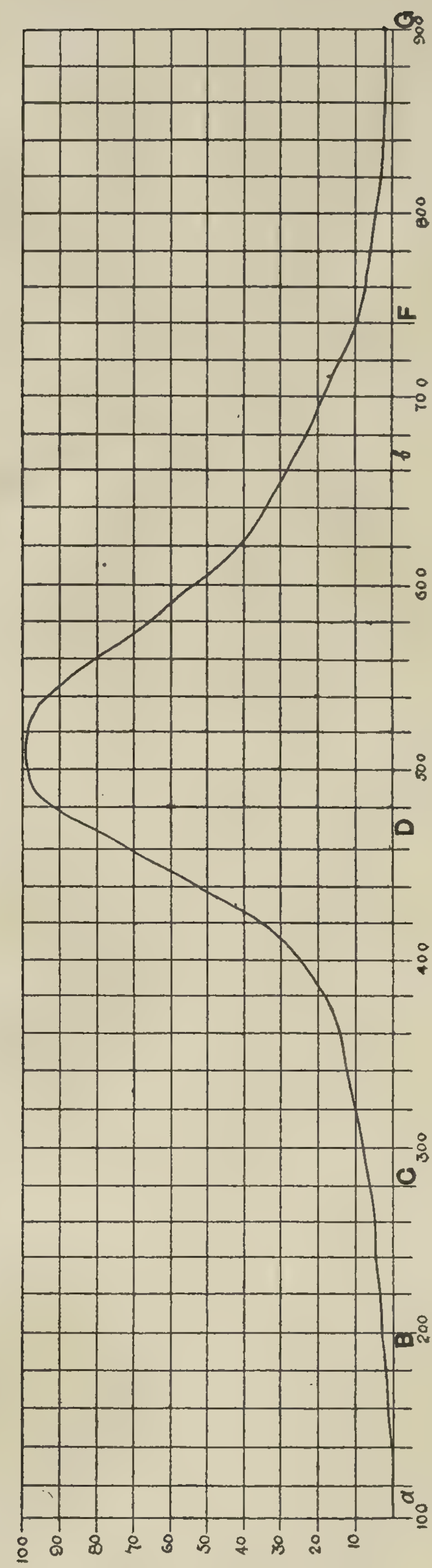
of white light which is equal to it in luminosity. Working in some similar manner the following scale of luminosity has been obtained, the spectrum being divided into 1000 parts between the fixed lines A and H as in the previous tables which have been given :—

LUMINOSITY OF THE SPECTRUM COLOURS.

Colour.	Position in spectrum.	Luminosity.
Dark red . . .	From 40·5 to 57 . .	80
Pure red . . .	,, 104·5 ,, 112·7 . .	493
Red	,, 112·7 ,, 138 . .	1100
Orange-red . . .	,, 158·5 ,, 168·5 . .	2773
Orange and orange-yellow	,, 189 ,, 220·3 . .	6985
Orange-yellow . .	,, 220·3 ,, 231·5 . .	7891
Greenish-yellow to green	,, 231·5 ,, 363 . .	3033
Blue-green and cyan blue	,, 390 ,, 493 . .	1100
Blue	,, 623·5 ,, 689·5 . .	493
Ultramarine . .	,, 493 ,, 558·5 . .	90·6
Blue violet . .	,, 753·5 ,, 825·5 . .	36
Violet . . .	,, 896 ,, 956 . .	13

This relative luminosity of the spectrum colours is also shown in a graphic form in Fig. 8, where the vertical lines show the position in the spectrum and the horizontal lines the luminosity. It will be seen that the most luminous portion is the yellow and orange, while the luminosity declines very rapidly on each side to the red or violet. It may be mentioned here that the luminosity of the colours as viewed by persons who may be colour blind will differ from the luminosity as seen by a person of normal sight. This subject will be referred to later on.

Another method of determining the luminosity of colours is to employ the apparatus shown in Fig. 44, which will be more fully described in Chapter III. A large disc of card coloured with some pigment, the luminosity of whose colour is to be determined, is placed on the spindle of a revolving apparatus; on this spindle are also fixed two overlapping discs of black and white paper, these being so arranged (see Chapter III.) that the relative proportions of black and


a
B
C
D
b
F
G
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400
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90
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70
60
50
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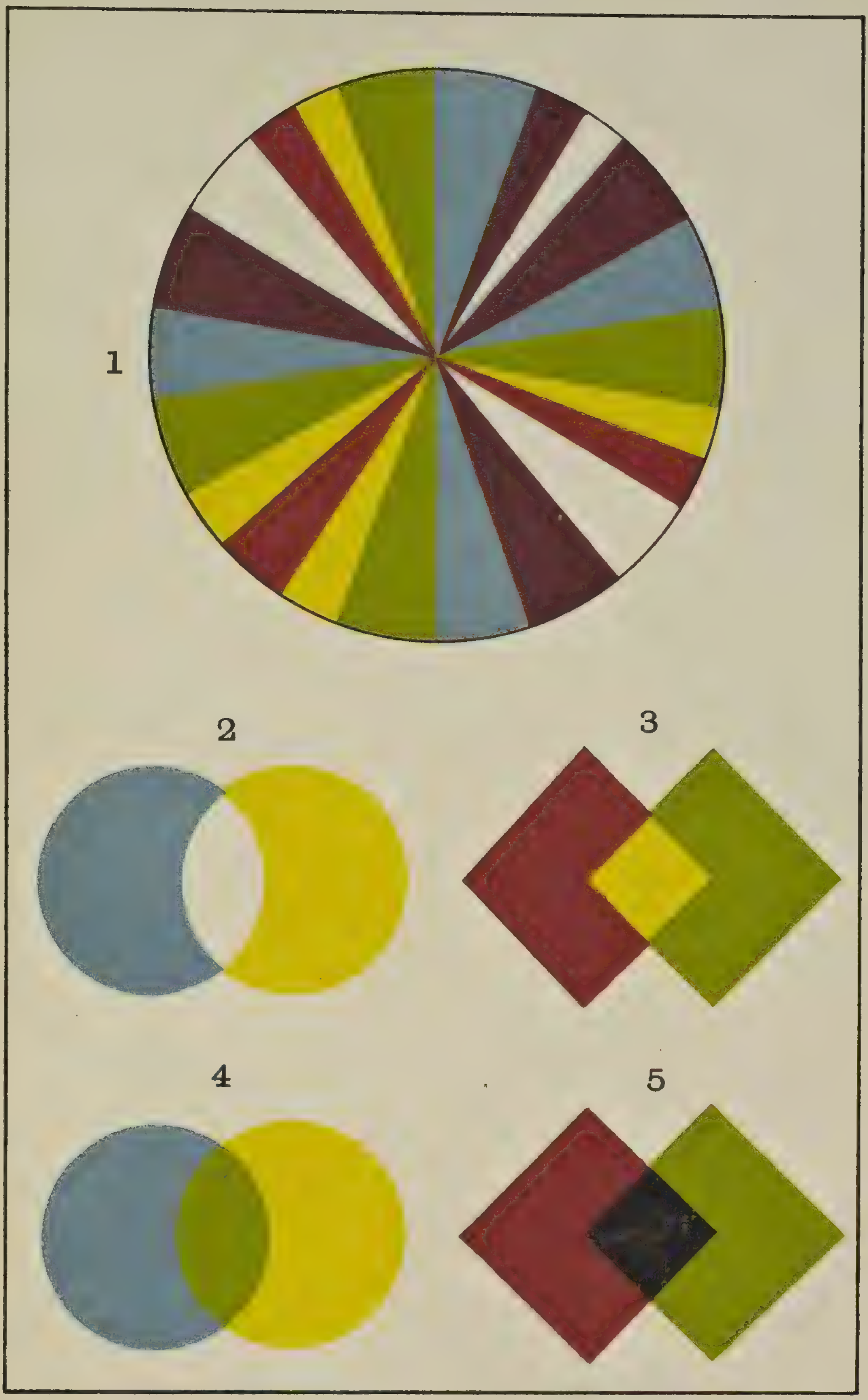
30
20
10

Fig. 8.

PLATE II.



white exposed can be varied. When all is ready the combined discs (which have, when at rest, the appearance shown in Fig. 47) are revolved ; the black and white then amalgamate and give the sensation of grey, which is more or less luminous according to the proportions of black and white exposed ; by varying these proportions a grey is obtained which will appear to have the same luminosity as the colour whose luminosity is to be measured. Then, assuming that white light has a luminosity of 100, the luminosity of the colour will be that of the quantity of white exposed in the black and white discs. There is a small error owing to the assumption that the black disc has no luminosity, whereas it has a small luminosity, usually about 4 to 5 per cent. of that of a white disc. The author has obtained the following results by this method :—

White paper	100
Vermilion	20·5
Orange red	40·3
Ochre	55·5
Chrome yellow	61·1
Emerald green	51·4
Green	50
Ultramarine	50
Blue	20·5
Umber	22·2

These measurements are not at all easy to make, but by taking the mean of several sets of observations a fair degree of approximation to the truth will be obtained.

Compared together with the eye it is possible for two colours, a red and a blue for example, to appear of the same degree of luminosity.

Extent of surface has some influence in modifying impressions of luminosity. A large surface of colour of low luminosity will overpower a small surface of colour of high intensity, and the two colours will appear to have the same luminosity. Artists are well aware of this, and often take

advantage of it in painting by introducing a spot or patch of a highly luminous colour into a mass of dark sombre colouring with very good effect.

The appearance of equal luminosity of different colours is, perhaps, a psychological one, and different observers may not regard the same pair of colours as being equally luminous, just as in different persons the perception of shade and tint in colours varies so much that in matching colour tints no two persons will obtain precisely the same results.

Purity.—The third constant of colour is *purity*. By purity of colour is meant the absence from a colour of any admixture of another colour or of white light. The standard of purity is the spectrum, the spectral colours being absolutely pure; they are, therefore, the standard of comparison for the light which comes from coloured objects, painted surfaces, etc. When the comparison is made it will be noticed that while such surfaces and coloured bodies may correspond in hue with some portion of the spectrum, yet the coloured surface will appear pale in comparison with the spectrum colour; this is due to the colour which is being compared being mixed with more or less white light. If, however, we make a mixture of the spectral colour with white light we shall reduce the intensity of the spectral colour to that of the coloured surface; and if the amount of white light thus added be measured, it necessarily gives the amount of white light admixed with the colour in question. Fig. 9 shows one method of mixing white light with the spectral colours.

In this drawing ABC represents a glass prism, S is a beam of white light passing through a hole, F, in a shutter, EG; this light, after passing through the prism, forms a spectrum, PT, on a screen, MN; another beam of white light from S passing through another hole in the shutter, EF, falls upon a mirror, L, and is reflected thence to the screen at O; by tilting the mirror, L, the white light may

be thrown upon any part of the spectrum, PT, and its effect upon the different colours observed.

Thus, for instance, vermilion, or rather the light reflected from a surface painted with that pigment, can be matched by mixing the light from a portion of the red end of the spectrum with 20 per cent. of white light. In a similar way it has been ascertained that emerald green reflects nearly the same amount of white light, and ultramarine about 25 per cent. The effect of white light being mixed with the colour is to reduce its intensity, to soften it and cause it to have less action on the eye; when the proportion of white

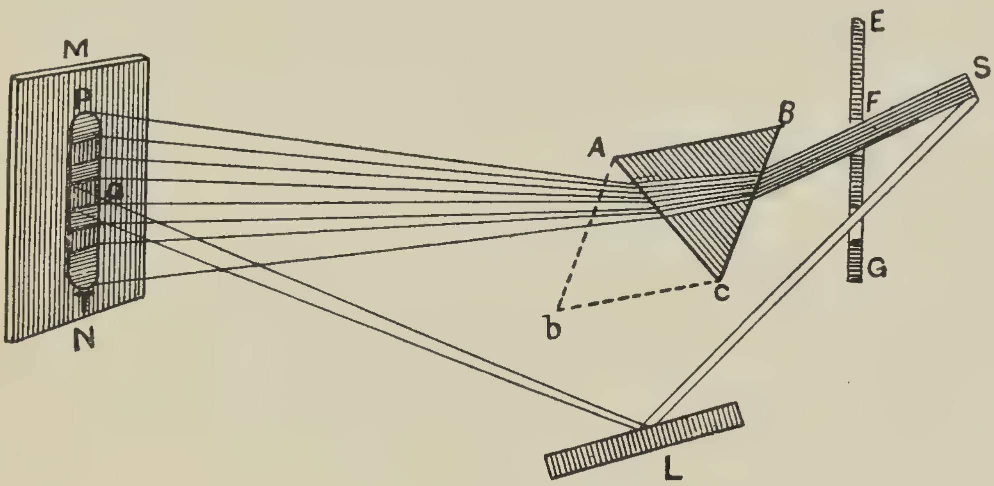


FIG. 9.

light becomes large then the influence of the coloured light is reduced so much that it becomes almost invisible, and we get what are termed *grey tints* varying in tone—reddish, greenish, bluish, etc.—according to the colour from which they are produced. This question will be best discussed in detail in another chapter.

III. **PRODUCTION OF COLOUR BY THE POLARISCOPE.**—When a ray of white light is passed through a prism of Iceland spar it undergoes what is known as *double refraction*, that is, the ray is split up into two rays, which pass out of the prism parallel to one another (see Fig. 10). These two rays possess

properties different from the original ray of white light; they have become what has been rather inaptly termed *polarised.* If the prism of Iceland spar be cut in two diagonally and the two surfaces cemented together, then it is found that while one ray passes on unchanged, the other ray is reflected to the side of the prism. A prism thus cut and arranged is known as a *Nicol's prism,* and forms a very convenient means of obtaining polarised light for experimental purposes; its action is shown in Fig. 11.

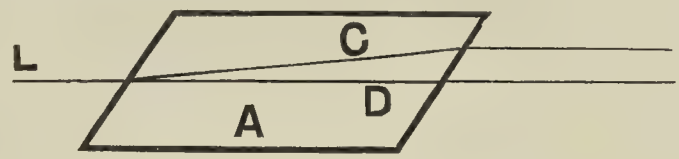


FIG. 10.

The Nicol's prism is shown with the diagonal cut AB, the two halves being cemented together with Canada balsam. A beam of light, C, entering the prism at D, becomes doubly refracted during its passage through the prism; on reaching the cemented surface AB, one of the two beams is reflected to the side of the prism, as shown in the drawing, while the other passes through the prism unaltered.

FIG. 11.

Another manner of obtaining polarised light is by reflection from a bundle of glass plates (see Fig. 13). It is found that, when a plate of glass is placed at an angle of 33° to the incident ray, the light which is reflected consists chiefly of polarised light; by employing a bundle of glass plates the effect is increased and a sufficient quantity of polarised light obtained to perform a large number of experiments. If the light from such a bundle of plates is caused to impinge upon

a Nicol's prism it is found that in one position of the prism the light passes through unchanged, while in a position at right angles of 90° to this one no light passes through. The same effect can be obtained if a second bundle of glass plates be employed; if this second bundle have their faces towards the polarising bundle then the light is reflected; while, if they have their edges towards the polarising bundle, the light is not reflected, but passes through the second bundle of plates. If a piece of selenite be interposed between the two bundles of glass plates its reflection on the second bundle will be more or less coloured, and on rotating the second

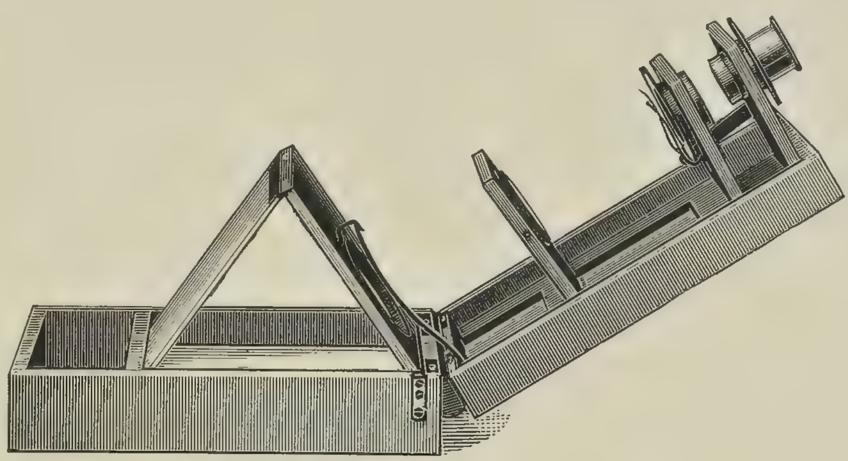


FIG. 12.

bundle of plates it will be found that the colour changes according to the position of the bundle. If a piece of rock crystal cut perpendicular to the axis of the crystal be interposed, colour will also be produced, and this colour will change as the second bundle of plates is turned round.

The instrument which is employed to produce polarised light is known as the *polariscope*. A simple form is shown in Fig. 12 taken from a photograph; while Fig. 13 is a diagrammatic representation of it. A bundle of glass plates, A, rests on the bottom of the box; light at the requisite angle is allowed to fall on this bundle of glass plates, which is known as the *polariser*, and being reflected upwards is then received in the

analyser, as it is called, B, which may consist, as in the instrument illustrated, of a Nicol's prism, or of a bundle of glass plates. The objects are placed, if large, on the support D; or, if small, at E, while at F is a lens which focusses the light on the objects when these are placed at E, or objects placed at D on the analyser B. C is a ground glass plate which diffuses the light that falls on the plates A. Polariscopes are now fitted to most microscopes, the polariser and analyser being made of Nicol's prisms, the former being placed under the stage of the microscope, while the latter

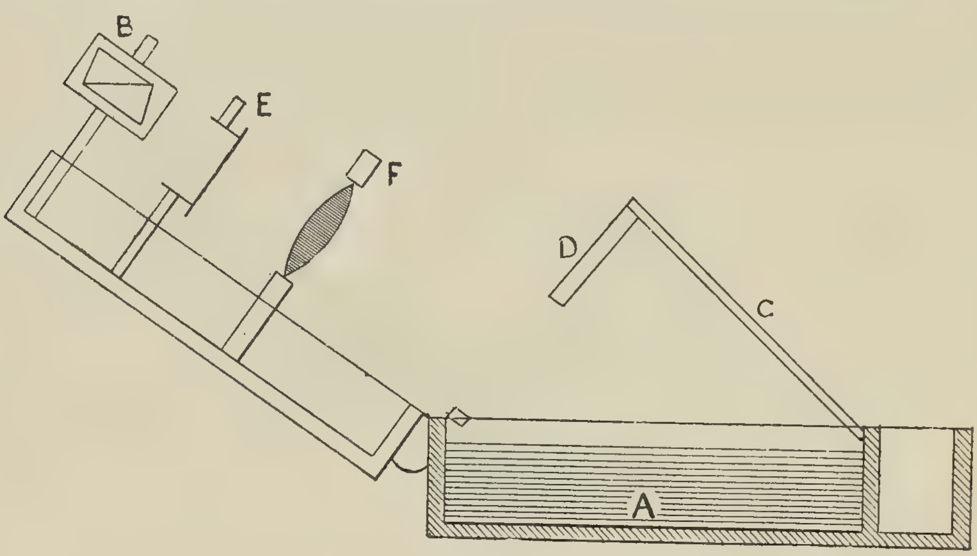


FIG. 13.

is placed just above the objective. Another form of the polariscope is shown in Fig. 14.

In this drawing, A is a bundle of glass plates, the polariser, while the enclosing tubes CD are so arranged that the light strikes the plates at the proper angle (see above); B is a similar bundle of glass plates, the analyser, in which the effects produced by the passage of the polarised light from A can be observed. This drawing shows a form of polariscope suitable for use either as a table polariscope for individual use or as a polariscope for the optical lantern for demonstrations to a number of persons.

Many substances, when placed between the polariser and analyser, give rise to the production of chromatic effects; thin plates of selenite, in particular, are useful for this purpose. The colour which is produced is dependent upon the thickness of the plate—thus one particular thickness will give rise to a yellow colour, another to a red, another to a green; if the plate of selenite be of uneven thickness then quite a gradation of colours will be produced. On rotating the analyser the colours will change, and when the analyser has been rotated through a quarter of a revolution the colour produced will be complementary (see Chapter III.) to that originally obtained. If a quartz plate be used, then, as the analyser is rotated, the

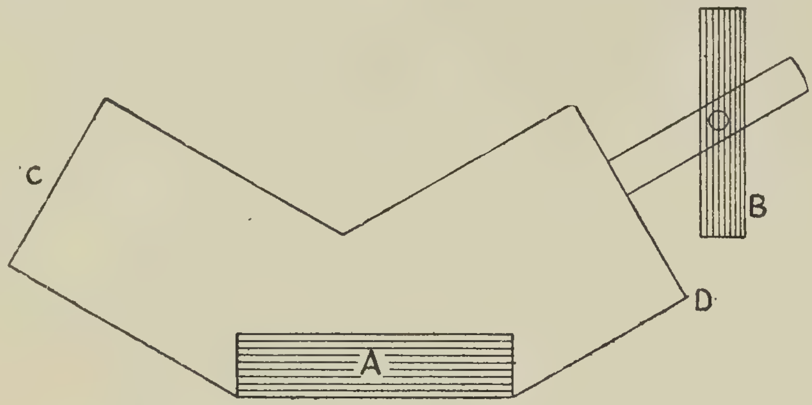


FIG. 14.

colours change in the order of the spectrum—red to orange, orange to yellow, yellow to green, and so on. Some quartz crystals require the analyser to be rotated to the right—such are known as right-handed (dextro-rotatory) crystals; others require the analyser to be rotated to the left—such are known as left-handed (lævo-rotatory) crystals. Some solid bodies, which do not produce any chromatic effect, have an action on the ray of polarised light. It has been stated above that when the analyser is rotated through 90° no light is transmitted; if now a substance be introduced between the polariser and the analyser, light will again be transmitted, while no colour is produced—this shows that the interposed sub-

stance has some action on the ray which passes through it. On rotating the analyser through a small angle the light is again obliterated, showing that the substance has a rotatory action on the ray of polarised light: some require the analyser to be rotated to the right, these are called dextro-rotatory bodies; while others require it to be rotated to the left, these are called lævo-rotatory bodies; it has been found that with many substances, as sugar, turpentine, etc., this property is of value from an analytical point of view and is largely taken advantage of. This feature of the subject is, however, beyond the scope of the present work.

When the ray of polarised light is sent along the optic axis of some crystals—potassium nitrate, tartaric acid, borax, calcite, sugar, ferrocyanide of potassium, phosphate of potassium, etc.—the analyser reveals a very fine effect; there is a series of concentric coloured circles round the axis of the crystal, while crossing them is a black cross; on rotating the analyser, the black cross gives way to a white one, while the concentric rings change their colour and assume the complementary hues; the brilliance of the colours is great. The character and degree vary with different crystals: in some cases the rings are sharply defined; in others, they pass gradually into one another; in some the black cross is prominent, while in others it is but faint. Some crystals are biaxial, and, therefore, two sets of coloured rings and two black crosses, which more or less intersect one another, are obtained.

When masses of crystals are allowed to form in thin layers on a piece of glass, these crystals, when viewed in the polariscope, give rise to very beautiful colour effects, which almost defy description; but when once seen they are not readily forgotten, on account of the harmony of colouring which prevails, and the immense variety of form and of colour which is presented by different substances.

Glass which has been heated and then suddenly cooled, or has by some means been subjected to a strain, also produces colour effects; sometimes the concentric coloured rings and black cross appear; at others, various effects, according to difference of conditions.

Starch grains often give rise to coloured effects when viewed under a microscope fitted with a polariscope; in some cases the colour effects produced suffice to distinguish one starch from other starches.

It is impossible and quite beyond the scope of this book to enter into a full account of the phenomena of polarised light and attempt an explanation of how and why they are obtained; the reader is referred to special books on the

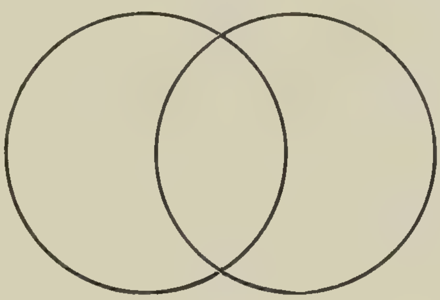


Fig. 15.

subject for that information. There is, however, just one other point that must be touched upon, as it has a bearing upon colour.

If, instead of using a Nicol's prism as an analyser, a simple prism of calcite be substituted, the light from the polariser being allowed to fall on this prism through a small hole, then, on looking through the eye-piece of the instrument, it will be observed that two white discs, more or less overlapping, will be obtained (see Fig. 15). If, now, between the polariser and the calcite prism be placed a thin plate of selenite, coloured discs will be obtained, the colours varying with the thickness of the film of selenite; but the chief feature about them is that the two discs are of different colours, which are comple-

mentary to one another—thus, while one may be green the other will be red, one yellow and the other blue, and so on. Where, however, the discs overlap, that portion is usually white; thus showing that by the union of two colours white light may be formed, see Plate 3, No. 5 *et seq.* This has a very important bearing on the theory of colour, which will be developed in a subsequent chapter.

IV. **COLOUR PRODUCED BY PHOSPHORESCENCE AND FLUORESCENCE.**—Certain compounds, notably the sulphides of barium, strontium and calcium, when exposed to bright light after having been reduced to a fine powder, and then taken into a dark room, are found to glow with light, differing in hue or tint in each case; such glow is known as *phosphorescent light.* Its nature or cause is not thoroughly understood, but research has shown that a large number of bodies are capable of exhibiting phosphorescence when first exposed to a bright light, as from burning magnesium, and then viewed in a dark place. There are some substances which exhibit this phenomenon more strongly under a vacuum than they do under ordinary conditions. The production of the so-called "luminous paint," which shines in the dark after exposure to light, is based on the property of barium and sodium sulphides in this respect.

When a solution of eosine in alcohol is viewed by transmitted light it appears of a pale crimson colour, yet when looked at direct it exhibits a beautiful yellow glow, which is known as *fluorescence.* Many substances are found to have this property, and are termed *dichroic.* Glass tinted or coloured with uranium has this property; when looked through it shows a pale yellow tint, yet it scatters a bluish-green light. Uranium glass has another property: if placed in a dark room and illuminated with violet light it does not reflect violet light, but appears to glow or to be self-luminous with a bluish-green light; this change of hue is very remarkable,

because it would appear as if the uranium glass had the property of changing the wave length of any light which falls upon it. A change in colour can only be accounted for by a change in the wave length of the emitted light. Stokes has made numerous experiments on this property of uranium glass and substances which act on light in a similar manner; he finds that in each case the wave length is affected and, further, that in each case this alteration is in the direction of increasing it. This property of fluorescence is possessed by many substances, *e.g.*, platino-cyanide of barium, thallene, etc., etc.

V. **PRODUCTION OF COLOUR BY INTERFERENCE.**—When certain oily bodies are thrown upon the surface of water they spread over it in the form of a very thin layer, and give rise to the production of a number of beautiful colours which, chameleon-like, rapidly change in hue and extent. These colours are produced in a peculiar manner; the waves of light impinging upon the film of oil undergo refraction and reflection, but the film is so thin that the waves of light reflected from its upper and lower surfaces clash with one another, whereby some are quenched, leaving the residue to pass forward to the eye of the observer as coloured light; the degree of quenching depends upon the thickness of the film, and as this is constantly changing, the colours change likewise. Interference colours are also produced when light is reflected from regularly marked surfaces where the markings are small in extent.

Interference colours are frequently met with in nature: the exquisite markings found on many beetles' wings, the iridescent hues found in many shells, the similar tints of fish scales, the colours on many birds' feathers are due to this cause. The colours on a soap bubble, those of many minerals, and those on many varieties of glass are due to interference.

For the purpose of showing the colours of thin films the apparatus illustrated in Fig. 16 may be used. This consists of a plano-convex lens, CD, and a double-convex lens, AB, both of long focal length, and three pairs of screws, PP, for

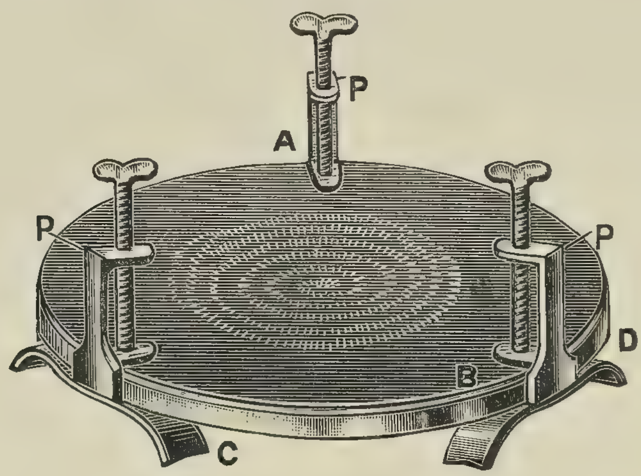


FIG. 16.

the purpose of screwing them together and producing a regular pressure at the point where the two lenses touch each other. By pressing the two lenses together there appears a black spot in the centre with a system of coloured rings or spectra concentred round it as shown in Fig. 17,

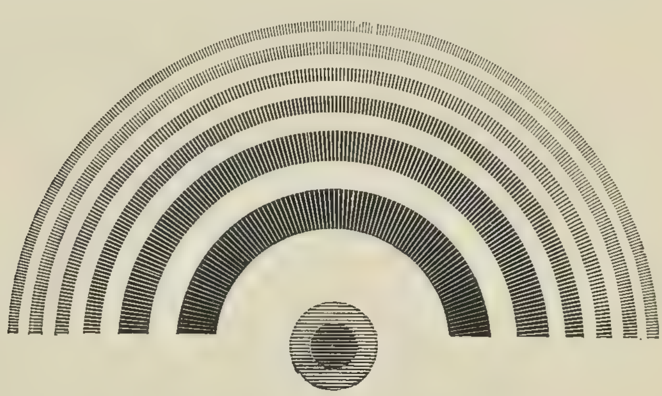
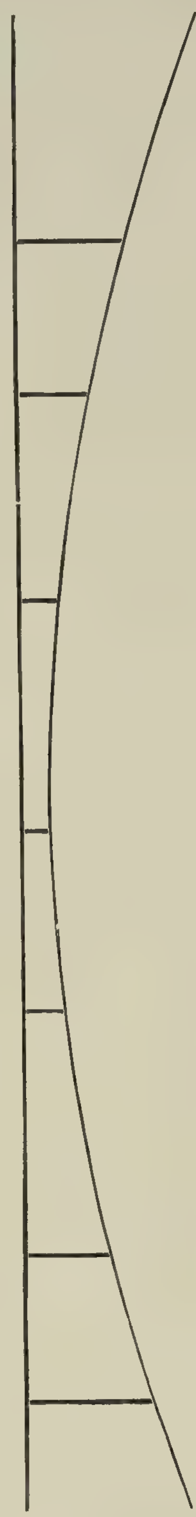


FIG. 17.

which represents about one-half of the system; the farther each system recedes from the centre the fewer are the colours in it. This is the effect visible by reflected light. If the



Reflected Tints.	Transmitted Tints.
Red.	Bluish green.
Green.	Red.
Red.	Bluish green.
Yellow.	Violet.
Green.	Red.
Blue.	Yellow.
Purple.	Green.
Red.	Blue.
Yellow.	Violet.
Green.	Red.
Blue.	Yellow.
Violet.	White.
Red.	Blue.
Yellow.	Violet.
White.	Black.
Blue.	Yellowish.
Black.	White.
Blue.	Yellowish.
White.	Black.
Yellow.	Violet.
Red.	Blue.
Violet.	White.
Blue.	Yellow.
Green.	Red.
Yellow.	Violet.
Red.	Blue.
Purple.	Green.
Blue.	Yellow.
Green.	Red.
Yellow.	Violet.
Red.	Bluish green.
Green.	Red.
Red.	Bluish green.

Fig. 18.

spectra be viewed by transmitted light, then the central spot appears to be white, and the system of spectra in colours which are complementary to those observed by reflected light. Fig. 18 shows the order of the tints passing from the centre outwards as seen by reflected and by transmitted light. It may be stated that a layer of air ceases to reflect light when the thickness is less than half a millionth of an inch; that with a thickness of more than seventy-two millionths of an inch it reflects white light, and that between these two limits it reflects colours in various degrees. In the same way water of a thickness of three-eighths of a millionth of an inch ceases to reflect light; above fifty-eight millionths of an inch it reflects white light, and other colours at intermediate thicknesses. Glass of a thickness of one-third of a millionth of an inch does not reflect light; at a thickness of fifty millionths of an inch it will reflect white light. Sir Isaac Newton, who investigated the colours of these films of air, has given the following table of the various spectra which can be observed, together with the varying thicknesses of air, water and glass at which they are obtained :—

SIR ISAAC NEWTON'S TABLE OF THE COLOURS OF THIN PLATES OF AIR, WATER AND GLASS.

Succession of Spectra, or Orders of Colours.	Colours produced at the thicknesses stated in the last three columns.		Thickness in millionths of an inch.		
	Reflected.	Transmitted.	Air.	Water.	Glass.
First Spectrum, or order of colours.	Very black.		$\frac{1}{2}$	$\frac{3}{8}$	$\frac{10}{31}$
	Black.	White.	1	$\frac{3}{4}$	$\frac{29}{31}$
	Beginning of black.		2	$1\frac{1}{2}$	$1\frac{2}{7}$
	Blue.	Yellowish-red.	$2\frac{2}{5}$	$1\frac{4}{5}$	$1\frac{11}{20}$
	White.	Black.	$5\frac{1}{4}$	$3\frac{7}{8}$	$3\frac{2}{5}$
	Yellow.	Violet.	$7\frac{1}{9}$	$5\frac{1}{3}$	$4\frac{3}{5}$
	Orange.		8	6	$4\frac{1}{6}$
	Red.	Blue.	9	$6\frac{3}{4}$	$5\frac{4}{5}$
Second Spectrum, or order of colours.	Violet.	White.	$11\frac{1}{6}$	$3\frac{3}{8}$	$7\frac{1}{5}$
	Indigo.		$12\frac{5}{6}$	$9\frac{5}{8}$	$8\frac{3}{4}$
	Blue.	Yellow.	14	$10\frac{1}{2}$	9
	Green.	Red.	$15\frac{1}{8}$	$11\frac{1}{3}$	$9\frac{5}{7}$
	Yellow.	Violet.	$16\frac{2}{7}$	$12\frac{1}{5}$	$10\frac{2}{5}$
	Orange.		$17\frac{2}{9}$	13	$11\frac{1}{9}$
	Bright red.	Blue.	$18\frac{1}{5}$	$13\frac{3}{4}$	$11\frac{5}{6}$
	Scarlet.		$19\frac{2}{3}$	$14\frac{3}{4}$	$12\frac{2}{3}$
Third Spectrum, or order of colours.	Purple.	Green.	21	$15\frac{3}{4}$	$13\frac{11}{20}$
	Indigo.		$22\frac{1}{10}$	$17\frac{4}{7}$	$14\frac{1}{4}$
	Blue.	Yellow.	$23\frac{2}{5}$	$17\frac{11}{20}$	$15\frac{1}{10}$
	Green.	Red.	$25\frac{1}{6}$	$18\frac{6}{10}$	$16\frac{1}{4}$
	Yellow.		$27\frac{1}{7}$	$20\frac{1}{3}$	$17\frac{1}{2}$
	Red.	Bluish-green.	29	$21\frac{3}{4}$	$18\frac{5}{7}$
	Bluish-red.		32	24	$20\frac{2}{3}$
Fourth Spectrum, or order of colours.	Bluish-green.		24	$25\frac{1}{2}$	22
	Green.	Red.	$35\frac{2}{7}$	$26\frac{1}{2}$	$22\frac{3}{4}$
	Yellowish-green.		36	27	$23\frac{2}{9}$
	Red.	Bluish-green.	$40\frac{1}{2}$	$30\frac{1}{4}$	26
Fifth Spectrum.	Greenish-blue.	Red.	46	$34\frac{1}{2}$	$39\frac{2}{3}$
	Red.		$52\frac{1}{2}$	$39\frac{3}{8}$	34
Sixth Spectrum.	Greenish-blue.		$58\frac{3}{4}$	44	38
	Red.		65	$48\frac{3}{4}$	42
Seventh Spectrum.	Greenish-blue.		71	$53\frac{1}{4}$	$45\frac{4}{5}$
	Reddish-white.		71	$57\frac{3}{4}$	$49\frac{2}{3}$

The production of colour by the falling of white light on coloured bodies, the sixth of the ways enumerated at the head of this chapter, is of sufficient importance to merit discussion in the next chapter.

CHAPTER II.

CAUSE OF COLOUR IN COLOURED BODIES.

VI. **BY THE ACTION OF COLOURED BODIES.**—We have now to discuss, as far as is possible, the reasons why any particular substance presents itself to our eyes as coloured. A final answer to this question cannot really be given, as we are still far from knowing why one substance should have a red colour, another one blue, and still another one green. For a final answer we shall have to learn more of the intermolecular structure of bodies than we know at present to ascertain why they should be able to select some of the rays of light and absorb or reflect them, while the other rays are not affected; possibly we may find that the molecules of these bodies are in such a state of motion as to enable them to neutralise light rays of certain wave lengths while not altering others.

We see coloured bodies under two conditions: in the first the light comes to our eyes through the body, or is transmitted, as is the case with stained glass, coloured solutions and liquids, etc.; while in the second case, the light is reflected from the object to our eyes. We will first consider colours produced by transmission through bodies and then the colour of reflected light.

Transmitted Colours.—When white light passes through coloured glass, of whatever colour that may be, and on to the eye of the observer as coloured light, then, to produce such light, it is evident that the glass or other body

Plate III.

1
2
3
4
5 6
7 8
9

must have had some action on the light; probably it has absorbed some of the rays which go to make up the white light that fell upon it and permitted others to pass on, the nature and degree of absorption depending upon the composition of the glass and the character of the colouring matter present therein.

To understand fully the nature of the absorption of light by coloured bodies we must observe the spectra of the rays which are transmitted, and compare these with the spectrum of white light. This is comparatively a simple matter: if the object to be examined is coloured glass then it suffices to hold it in front of the slit of an ordinary spectroscope; or, in the case of coloured solutions or liquids, to hold a glass vessel containing them in front of the slit. In the case of dyes from coal tar their absorption spectra can be very conveniently obtained by a plan described by Mr. Arthur Dufton: ordinary photographic dry plates are taken, and the silver salts removed from them by placing the plates in a bath of hyposulphite of soda and thoroughly washing them afterwards; the plates are next immersed in a weak solution of the dye stuff. In the case of the basic and direct dyes such as Magenta, Safranine, Chrysoidine, Chrysamine, Benzo blue, etc., no addition need be made to the solution; while in the case of the acid and azo colours, such as Acid green, Naphthol yellow, Orange, Eosine, etc., a few drops of acetic acid may be added. Any depth of colour may be obtained on the plates within limits by regulating the duration of immersion in the dye solution; in time, however, the gelatine film on the plate seems to get saturated with colour, and no further increase in depth is obtainable. The gelatine plate so obtained may be placed in front of the slit of the spectroscope and the spectra of the colour obtained. The author has made numerous plates in this way, and finds it an easy and yet efficient mode of working.

When we examine by means of the spectroscope the light transmitted by red glass, we see that the spectrum which is obtained is not a complete one compared with the spectrum of white light; we only see the red and a part of the orange portions of the spectrum—all the rest of the colours of white light have been absorbed in its passage through the glass. This is shown in Fig. 19, where the spectra of white light and red glass are compared together. It will be seen that the red glass only permits the red, orange and part of the yellow to pass, while the rest of the yellow, all the green, blue and violet rays are suppressed or absorbed, and are prevented from being transmitted. In connection with the

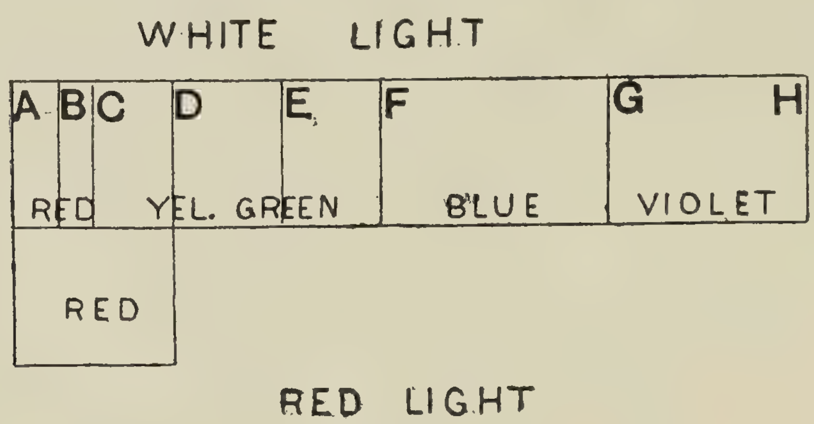


FIG. 19.

fluorescence colours we have seen that the phenomenon is brought about by the fluorescent body acting on the light which falls upon it and changing its wave length; hence the question may arise, May not a red substance so act upon the light which falls upon it and change it into red light? That this is not so is shown in several ways, as will be demonstrated in the following chapters; but one simple way may be given here. If the spectrum of white light be thrown on a wall or screen and observed through a piece of red glass, we shall see the red portion of the spectrum, the rest being apparently eliminated; if a piece of green glass be substituted, then we shall see the green portion only, the red, yellow, blue and

violet being absorbed and their transmission prevented; in the same way a piece of blue glass will only permit the passage of the blue and violet rays. It might be inferred that if the coloured glass exercises a degree of selection on the light which is presented to it, and will only allow certain rays to pass through, then, if red glass will stop all but the red rays and green glass all but the green rays, a combination of both should stop all rays from passing; this is actually the case—a piece of green and a piece of red glass when superposed one on the other will stop all light from passing through them, and on looking through them they will appear black in consequence.

We have in the foregoing remarks assumed that a red glass only transmits red rays; it, however, does more than this. If we take a spectroscope and fix across one half of the slit a piece of red glass we shall see, first, an ordinary luminous spectrum, and, secondly, the spectrum of the red glass; by this means we shall be able to compare the two together and better observe the effect of transmitting the light through the red glass. In the first place we shall see that the glass not only prevents the transmission of some of the colours, but also that the intensity of those which are transmitted is very considerably reduced. The reduction in intensity can be measured, but it is difficult to show the relative intensity by shading on paper. One way of doing this is shown in Fig. 20, which represents the spectrum of red glass. Here the whole rectangle indicates the extent and intensity of the light of a complete spectrum. The rectangle AHNO shows the space occupied by the spectrum of white light, while the shaded portion gives some idea of the extent and intensity of the light transmitted by the red glass; the height NL of this portion shows the relative intensity of the light transmitted compared with the light of the corresponding portion of the spectrum of white light. We see from this

that while red glass permits the transmission of the red rays, it also allows the orange and, in a greatly diminished degree, the yellow rays, together with even a small proportion of the green and blue rays, to be transmitted; but the violet rays are completely cut off. The degree of luminosity of the greenish-yellow to blue rays which the glass transmits being

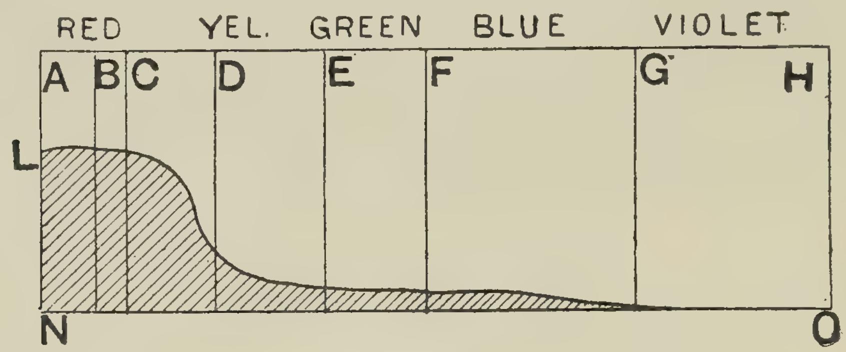


FIG. 20.

so small, it is to the eye overshadowed by the preponderance of red rays; consequently the light from the glass appears red, for it is only when we view the red light through the spectroscope that we see that it contains yellow, green and blue light to a small extent. It must, however, be pointed

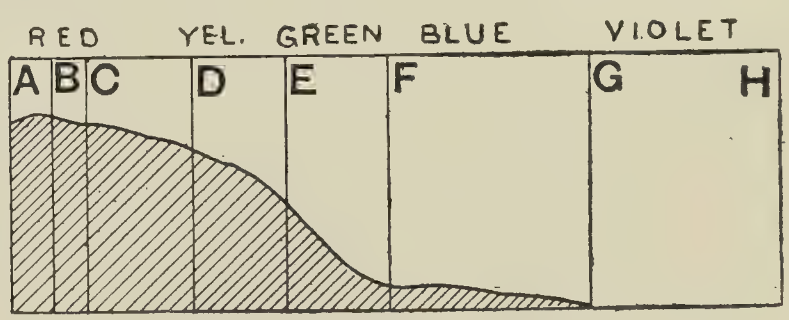


FIG. 21.

out (as will be seen more fully presently) that the character and extent of the rays which may be transmitted vary with different kinds of red glass; some may cut off more of the green and blue rays than others; and some may transmit more of the orange and yellow rays. Compare Plate 1, in which are given the spectra of various red bodies.

As another example we may take a glass of an orange-yellow colour, the spectrum of which is shown in Fig. 21. Here we see that the glass transmits the red, orange and yellow rays with a slightly diminished intensity; the green with a considerable diminution of intensity, a little of the blue and a very small portion of the violet; the eye sees, as it were,

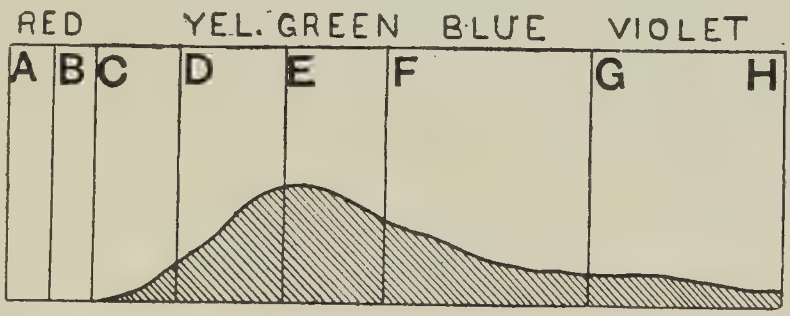


FIG. 22.

the mean of these colours and calls the glass orange-yellow. Fig. 22 shows the absorption spectrum of a piece of green glass. In this case the glass materially reduces the intensity of the light; this is shown by the curve barely extending to half the height of the normal spectrum in the green portion, while it tapers off towards the yellow on one side and the

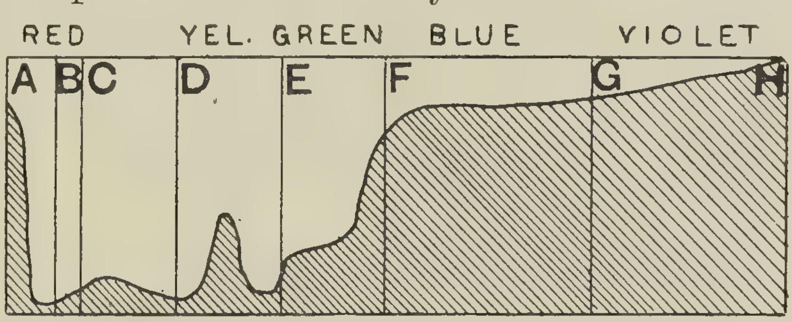


FIG. 23.

violet on the other. It will be noticed that the glass permits the violet rays (but with diminished intensity) up to the H line to pass, while it stops all the red.

In Fig. 23 is shown the spectrum of a blue glass. This is of a much more complex character than any of the others. Every part of the normal spectrum is represented, the green-

blue to violet being in considerable amount; while a portion of the spectrum close to the A line is shown, there is but little of the orange-red near the B line, a little more of the orange in the neighbourhood of the C line, a little of the yellow and somewhat more of the greenish-yellow in the space between the D and E lines.

The quantity and character of the light which is absorbed by coloured glasses, or coloured media of any kind, depend upon the thickness or depth of colouring; thus red colouring matter, when in a thin layer, may permit some of the green and even small quantities of the blue and violet rays to pass, while, in a thicker layer, only red, and, perhaps, some of the green rays may pass through; while in a very thick layer none but red rays may pass. This explains how it is that the dyer may, by using more or less dye-stuff, produce so many varieties of tint, varying somewhat in hue, from the same colouring matter, because when only a small amount of dye-stuff is applied it is not in sufficient quantity to neutralise, so to speak, the white light which is reflected from the fibre on which the dye-stuff is applied; as the quantity of dye is increased there is less white light reflected, and the colouring matter then shows its normal hue.

Absorption Spectra of Colouring Matters.—In the practical applications of dyes for the colouring of textile fabrics of all kinds we are accustomed to mix them together in a variety of ways to produce any particular shade that may be desired; thus, for instance, a green is dyed on wool by using picric acid or Tartrazine with indigo extract; the first named is a yellow dye-stuff, the last a blue dye-stuff. Browns are dyed by uniting archil (a red dye) with indigo (a blue dye) and Acid yellow (a yellow dye) in suitable proportions. To understand how these various combinations, and others of a similar character, can bring about the desired colour we must know their colour absorptive action on white light.

This is done by observing their absorption spectra. On Plates 1 and 3 and in Figs. 24 to 29 are given the absorption spectra of many of the most used colouring matters and dyes.

In Plate 1, No. 2, we have the spectrum of Picric Acid. This shows all the red, yellow and green, and a portion of the greenish-blue, but the rest of the spectrum is extinguished. We see now that picric acid is capable of dyeing greenish-yellow shades because it contains the green and a portion of the blue.

No. 3 of the same plate shows the spectrum of Tartrazine. This colouring matter dyes much redder shades than does picric acid, and the spectrum shows why this is so, for while the red, orange, yellow and green are present, the blue and violet are completely absorbed. The red and green constituents of these colouring matters, when they enter the eye, give rise to the sensation of yellowish-white; hence we only perceive the appearance of yellow, of a reddish tint, on account of the greater predominance of red and green rays over those of the former colour.

No. 4, Plate 1, represents the spectrum of Scarlet R. We have here the complete extinction of the violet, blue, green and yellow portions of the spectrum, leaving only the red and the orange. As a contrast to this we have another red dye Azorubine, shown in No. 5; this dye-stuff produces full crimson shades, and the reason is that only the red rays are permitted to pass through, while the rest are completely absorbed.

No. 6, Plate 1, is the spectrum of a light shade of Magenta. In this case the rays absorbed are the yellow, green and greenish-blue; but in dark shades of Magenta there is more complete absorption, and only the extreme red rays are permitted to pass.

In No. 7, Plate 1, we have the spectrum of Safranine; in

this there is only an absorption of the yellow, green, and a portion of the blue rays, with partial absorption of the violet, the whole of the transmitted rays making on the eye the impression of a violet-red, which is the hue peculiar to Safranine.

No. 8, Plate 1, is the spectrum of Rhodamine which dyes pink shades. The spectrum shows the reason of this by the fact that Rhodamine only absorbs yellow, green and green-blue rays, while the violet and red rays transmitted give rise to the sensation of pink to the eye.

Another red dye-stuff, the spectrum of which is given in Plate 1, No. 9, is Eosine, shown in a dark shade, which indicates the transmission of red, orange, and a small portion of the yellow. In light shades there is absorption of the green and greenish-blue only, the other colours being transmitted.

In No. 10, Plate 1, is shown the spectra of Acid Green. The green and green-blue rays only are transmitted, while all the other rays are absorbed.

In No. 11 on the same plate is the spectrum of Indigo extract. Here the blue, bluish-green, part of the red and small portions of the green and yellowish-green rays are transmitted, and the orange, yellow and violet are absorbed.

No. 1, on Plate 3, is the spectrum of another blue dye-stuff. Cyanol, which dyes an extremely pretty blue. It shows the transmission of the green, blue, part of the violet and a small part of the red rays, the sum total of which gives rise to the sensation of blue to the eyes.

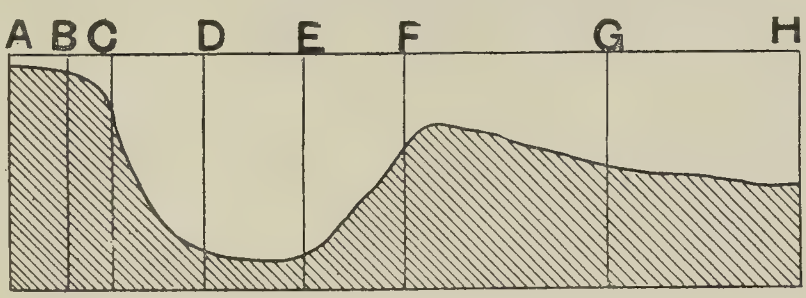
In No. 2 of the same plate we have the spectrum of Aniline blue. This shows the transmission of a portion of the red, some of the green, all the blue and part of the violet rays, while the orange, yellow and extreme violet rays are absorbed.

No. 3, Plate 3, is the spectrum of Methyl Violet, which

shows the transmission only of the extreme red, part of the blue and part of the violet rays, the rest being absorbed.

No. 4, Plate 3, is the spectrum of Iodine Green. It shows an absorption of part of the red, orange and yellow, and of the blue and violet rays.

It is the custom of dyers to mix dye-stuffs together for the purpose of obtaining certain shades; thus, for instance, Indigo extract and Picric Acid are employed to produce green. Now this green is produced, not because in the abstract blue and yellow produce green, but because they both allow green light to go through, the Indigo extract absorbing the red and



NAPHTHALENE RED

Fig. 24.

the yellow rays, and the Picric Acid the blue and the violet rays; thus only the green rays are permitted to pass. A mixture of Methyl Green and Methyl Violet produces a blue; this is because blue is the colour common to both dye-stuffs. The Violet absorbs the green and yellow, while the Green absorbs the red and the violet; thus the blue only is transmitted. The combination of Azorubine with Acid Green produces a black; an examination of the spectra of the two colours shows why this is so, inasmuch as the Azorubine permits only the red to pass through, while the Green transmits only the green and blue rays. When both colouring matters are used together no rays pass through, the result is the production of a black; this proves that black is the result

of the absence of light, and is not produced by the addition of one coloured light to another.

Fig. 24 is the spectrum of Naphthalene Red. This product dyes bluish-red tints, and the reason is visible from an examination of the spectrum, which shows the transmission of the

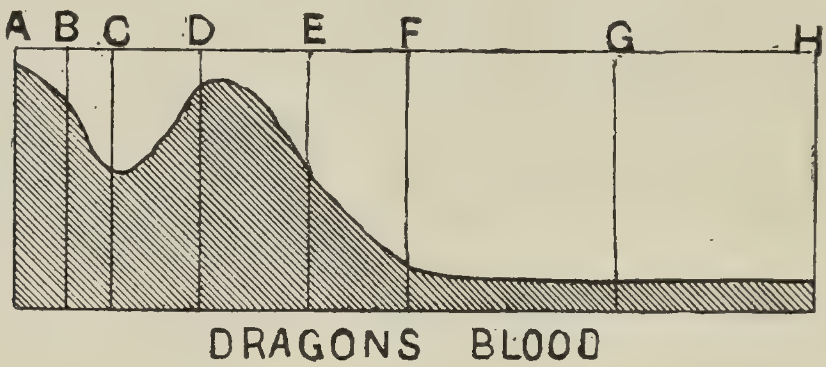


FIG. 25.

red rays, together with a little of the violet, some of the blue, and a small quantity of the yellow.

Fig. 25 is the spectrum of Dragon's Blood, which shows the transmission of the red and the yellow rays, and but a small quantity of the green, blue and violet.

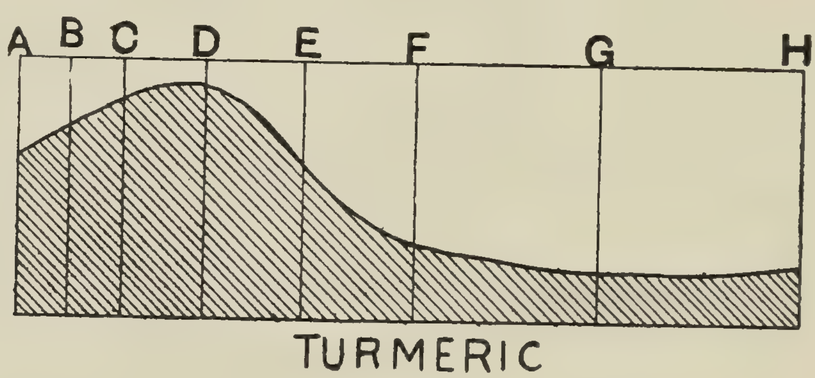


FIG. 26.

The spectrum of Turmeric, a yellow dye-stuff which produces somewhat orange shades, is shown in Fig. 26. Here we see that yellow forms the principal portion of the transmitted rays; some of the red and the lighter greenish-yellow rays are also transmitted.

Figs. 27 to 29 show the absorption spectra of certain alcoholic solutions of various colouring matters. Alizarine, Fig. 27, shows a transmission of the red, orange and yellow, with a little of the green and but a small quantity of the blue and violet. The sister colour, Purpurin, which dyes somewhat

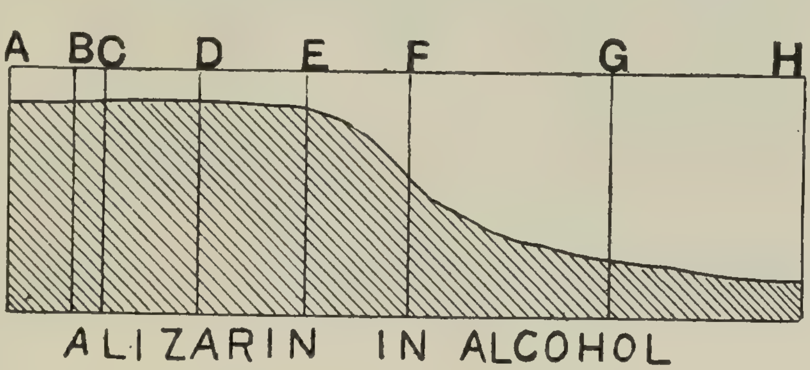


FIG. 27.

bluer shades than Alizarine, has the absorption spectra shown in Fig. 28. Cochineal solutions, Fig. 29, show the transmission of red and blue rays, while only the green are absent to any extent.

The principal difficulty in colour phenomena is to account

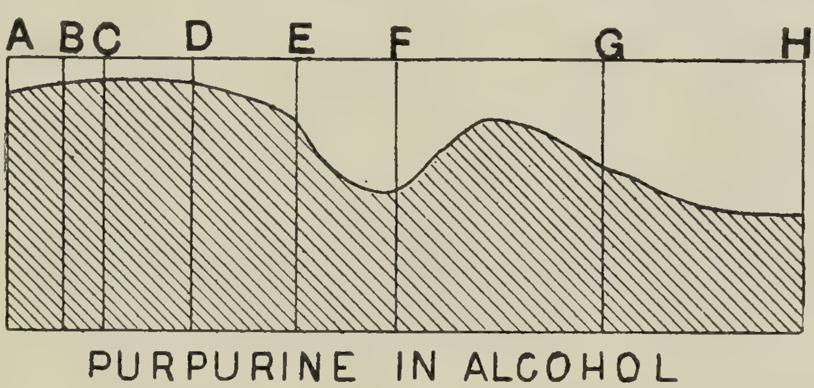


FIG. 28.

for the production of such shades as browns, olives, greys and similar shades, which often pass under the term of *tertiary* colours. An examination of the absorption spectra of such shades solves the difficulty. For instance, Bismarck Brown, which dyes cotton in reddish-brown or orange-brown

shades, has a spectrum which shows both red, orange-yellow and green shades, this spectrum being very similar to that produced by an orange colour ; there is, however, much more diminution in the intensity in those portions of the spectrum, in other words, the luminosity of the spectrum of Bismarck

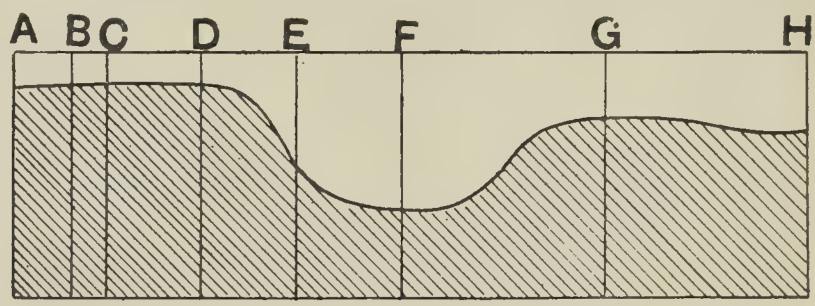


Fig. 29.

Brown is much less than that of the orange dye; we may regard Bismarck Brown as a poor or degraded orange without much error.

It is a common feature in dyeing to produce olive by using a mixture of Acid Green and Orange G. If the spectrum

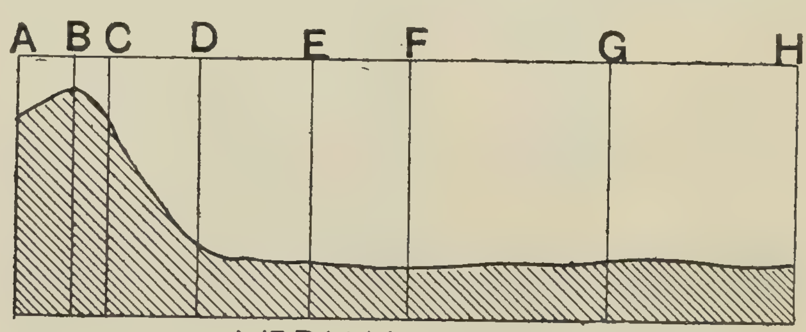


Fig. 30.

of the olive colour is examined, it only shows a small portion of the green in very diminished intensity; therefore we may regard olive as a degraded green.

Greys are produced in dyeing by mixing red, yellow and blue dye-stuffs in various proportions. When the spectra of these shades are examined (when dyes are used in their pro-

duction) they usually show the presence of two points of light, one in the red and the other in the bluish-green. Now the red and the green together produce the sensation of white; but owing to the considerable degree of absorption there is a very low luminosity, which shows itself to the eye

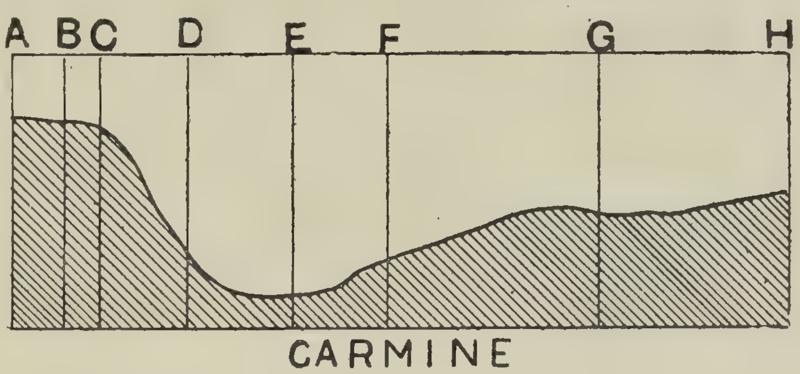


FIG. 31.

as a grey; its production in this way is equivalent to mixing a black and white together, the tint of grey produced depending on the relative proportion of the dyes used.

Pigments, also, give absorption spectra, which may be examined in two ways, either from the light that is reflected

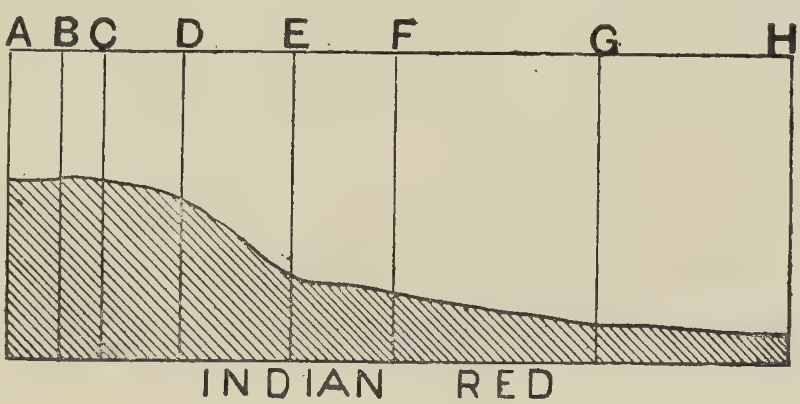


FIG. 32.

from them, or from the light that is caused to pass through a thin layer of the pigment. In either case, similar spectra are obtained. Figs. 30 to 42 show the spectra of the most common pigments in use by painters. In Fig. 30 we have that of Vermilion, which shows that this pigment reflects the

red and yellow rays and a small proportion of the other colours. In Fig. 31 we have that of Carmine, which differs from that of Vermilion in there being a larger proportion of blue and violet rays; to which circumstance is due the more crimson hue of Carmine. In Fig. 32 is given the spectrum of

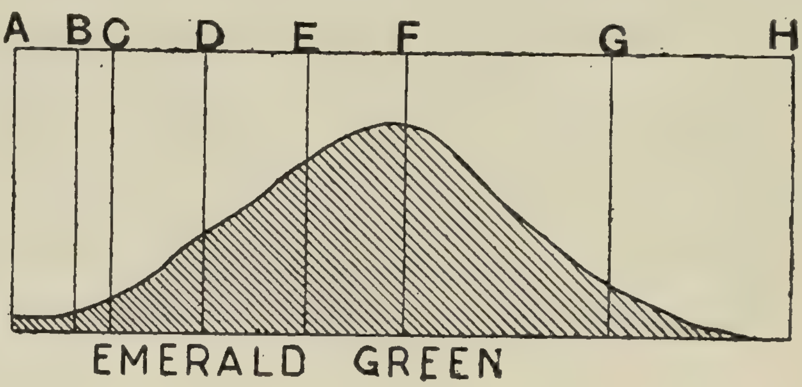


FIG. 33.

Indian Red. In this the red, orange and yellow rays are transmitted, as also a small proportion of the blue and violet rays. It is somewhat of interest to compare the spectrum of Vermilion with that of Indian Red; the former pigment is of a bright scarlet colour, while the latter has a dull reddish

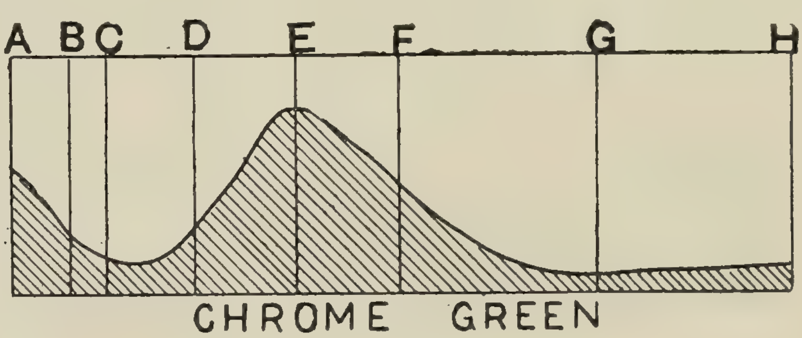


FIG. 34.

hue. The spectra show that, while in the case of the Vermilion, the red and orange rays are transmitted in almost their full intensity, in Indian Red there is a very considerable loss in intensity in these rays, and it is to this circumstance that the much duller colour of that pigment is due. In Fig. 33 is given the spectrum of Emerald Green, from which it

will be seen that while the green rays are present in almost their full intensity, there are present small proportions only of the other rays of the spectrum. In Fig. 34 is given the spectrum of Chrome Green, where we have the green rays in nearly their full intensity, but there is also reflected a portion

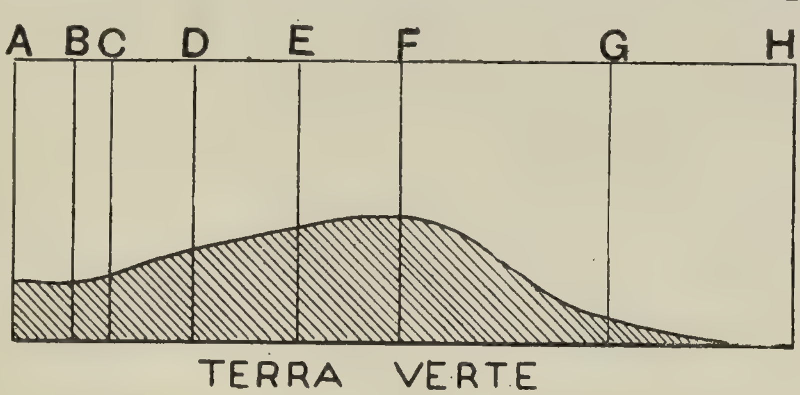


FIG. 35.

of the red rays and some of the blue and violet rays, and it is to the presence of these latter shades that we must ascribe the deeper tone of Chrome Green in comparison with Emerald Green. In Fig. 35 we have the spectrum of Terra Verte; this colour is more renowned for its permanence than for its

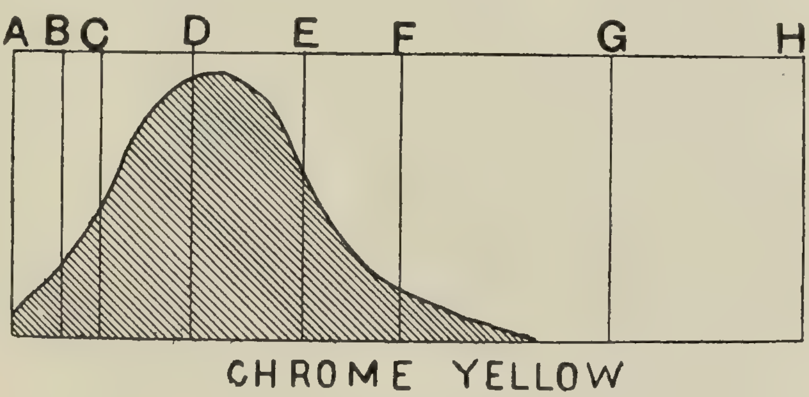


FIG. 36.

brilliancy. Its hue is that of a greyish-green; from the spectrum we gather that while the green rays are present, there is also a fair proportion of the red, orange and yellow rays as well as a little of the blue and violet rays; the intensity of all these rays is, however, very slight; this low

intensity and the combined action of the blue and red rays, where viewed by the eye, cause Terra Verte to appear of a greyish hue.

In Fig. 36 we have the spectrum of Chrome Yellow. It shows that this pigment reflects a large proportion of the

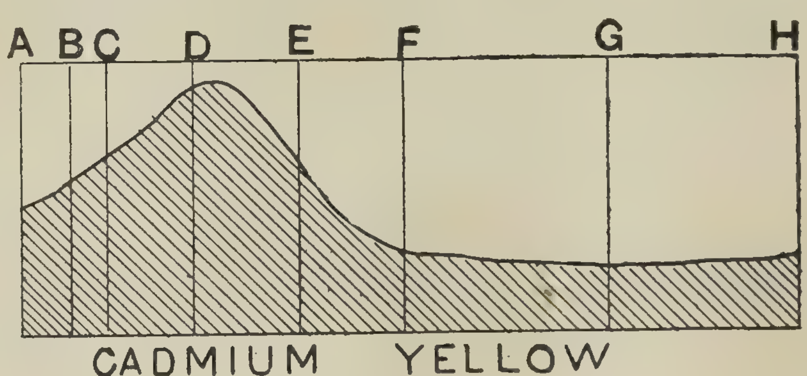


FIG. 37.

yellow and green rays, with some small quantity of orange and blue. Cadmium Yellow is a pigment of a rather more orange tone than Chrome Yellow. This fact is explained by examination of its spectrum, which is given in Fig. 37, which shows that, while yellow rays are strongly represented, there are also more violet and red rays than in Chrome Yellow.

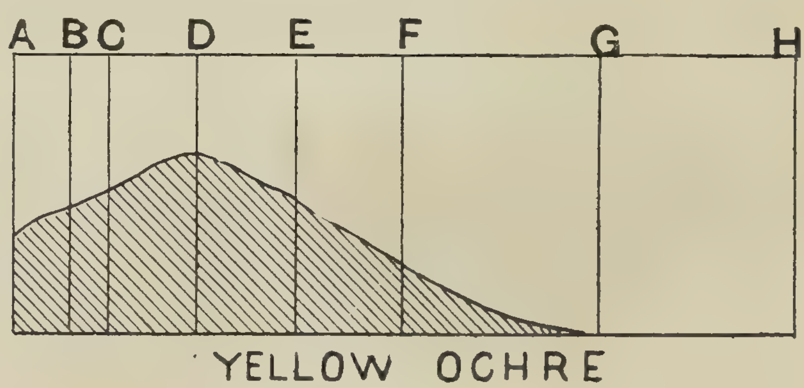
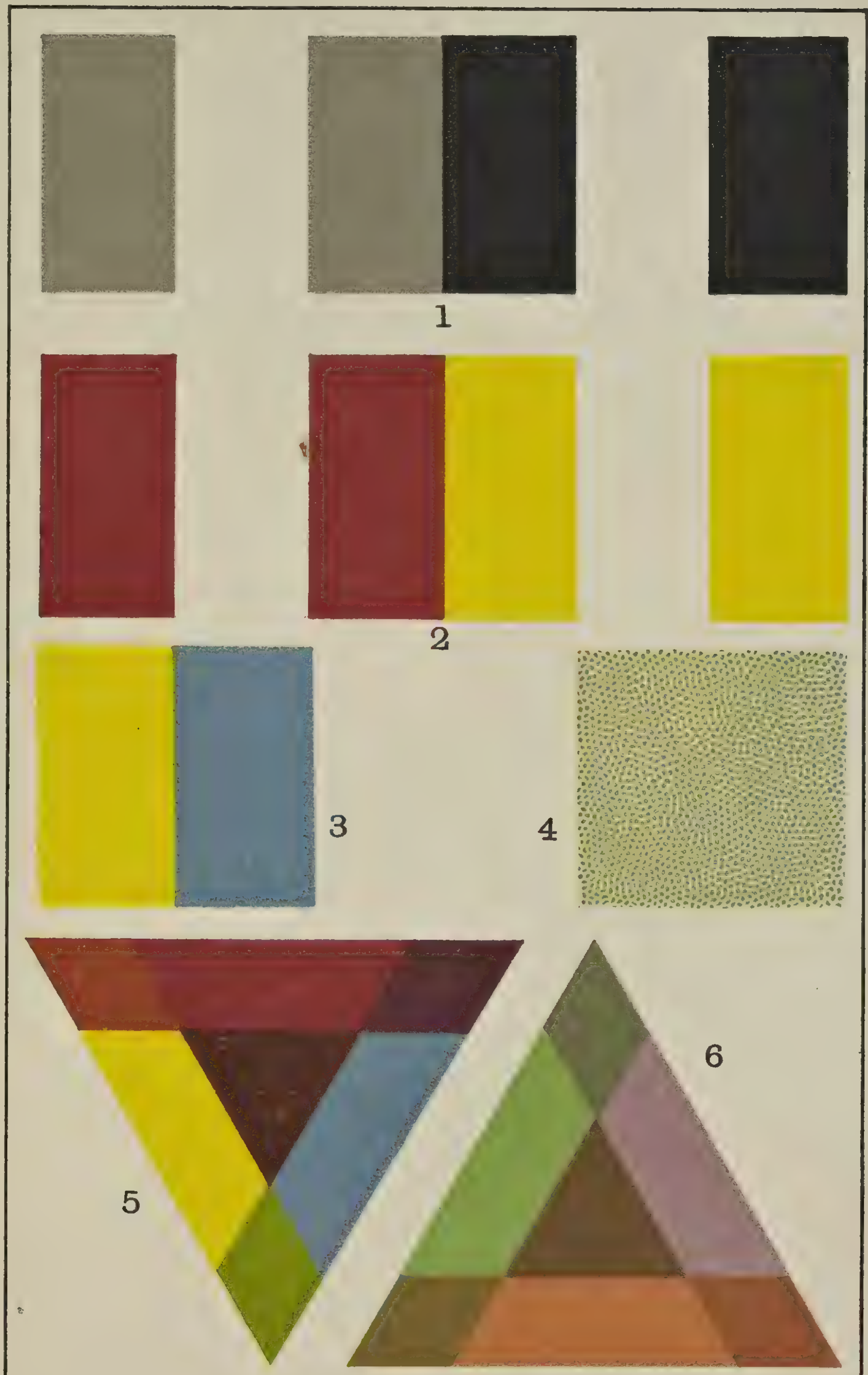


FIG. 38.

The spectrum of Yellow Ochre is seen in Fig. 38, which shows the presence of yellow, some red, and a little green; the intensity of the rays is small as compared with Chrome Yellow, and to this fact the dull hue of Yellow Ochre is to be

PLATE IV.



ascribed, while the greater proportion of red reflected accounts for its reddish hue.

In Fig. 39 we have the spectrum of Ultramarine, a pigment of a bright hue. We see that, while there is a small quantity of the red and yellow rays, there is a great predominance of

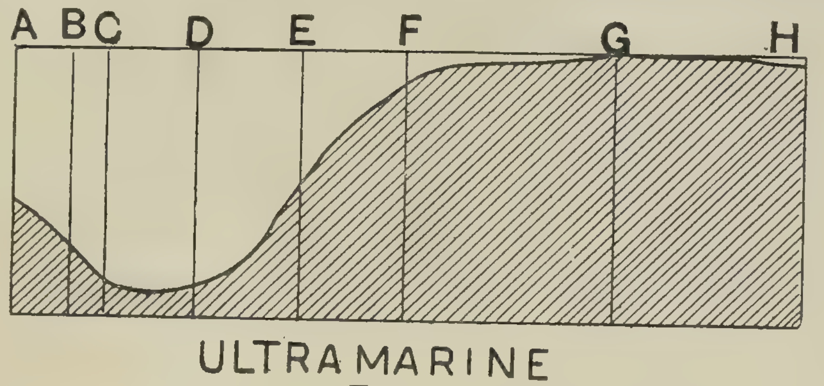


Fig. 39.

the blue and violet rays to which the colour of the pigment is due.

Ultramarine Green is shown in Fig. 40, where we see the green rays are in the greatest predominance, while there is

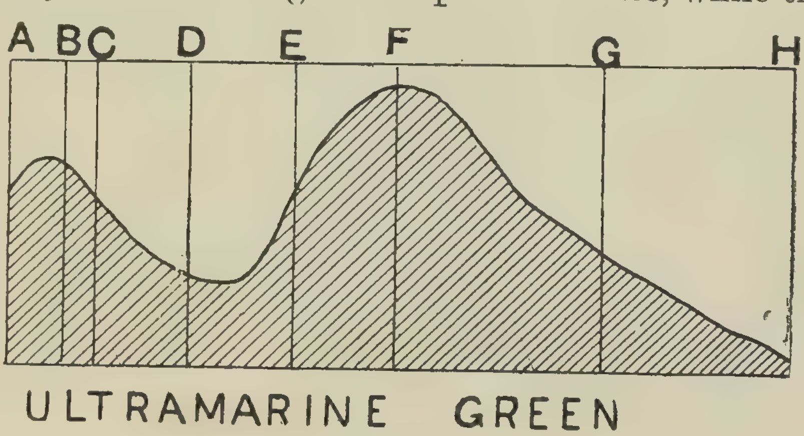


Fig. 40.

only a small proportion of the blue and orange rays of a low intensity.

In Fig. 41 we have the spectrum of Smalt, which is a blue pigment of a violet hue and low intensity. The spectrum shows that almost every ray of colour is present in greater or less quantity, and that the red, the blue and

the violet rays are much more prominent than the other rays. The blue colour of this pigment is evidently due to the fact that the red and green on the one hand, and the blue and yellow on the other, are present in just the proportions required to produce white light, leaving the violet and

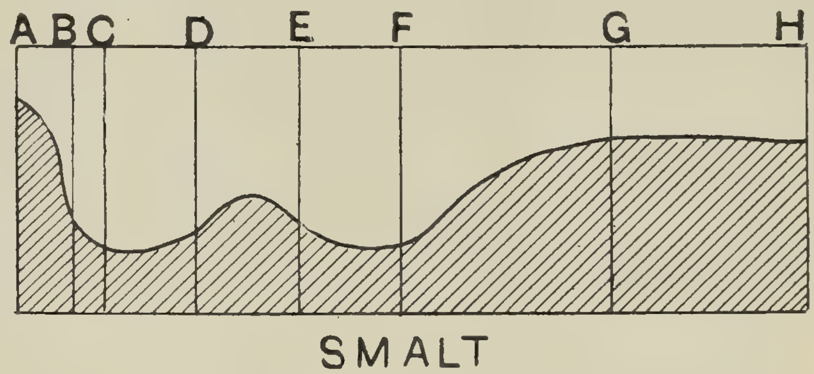


Fig. 41.

a portion of the blue to impress themselves on the eye. The low intensity of the colour is due to only a portion of each ray being transmitted.

The well-known pigment, Prussian Blue, has a spectrum (Fig. 42) of a different character to either Ultramarine or Smalt.

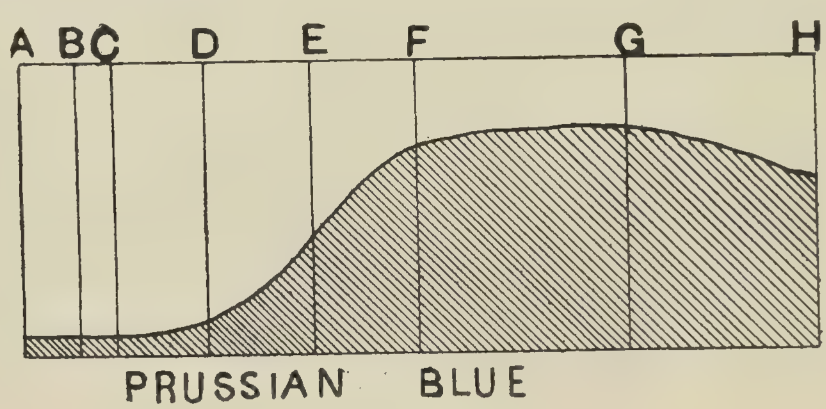
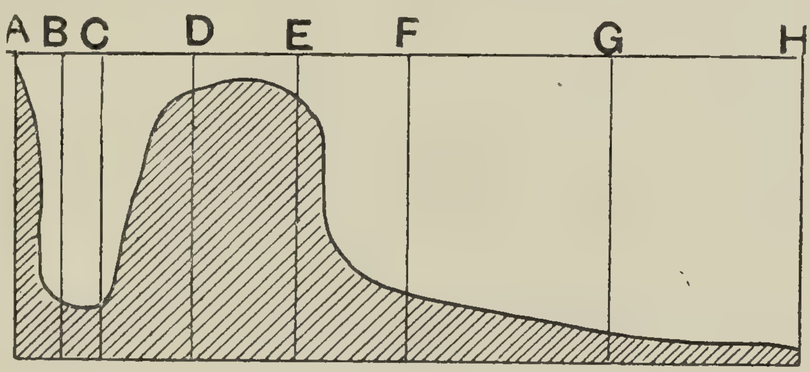


Fig. 42.

In this the blue and green rays have a greater predominance, the violet is also present, but there is little yellow or red rays. The deep colour of Prussian Blue is undoubtedly due to the fact that the principal rays are transmitted in almost their full intensity.

We may conclude this section of the subject by an examination of the green colouring principle to which vegetation owes its hue, Chlorophyll. An examination of the spectra of the green colours which have already been given will show that with them the red is absent or nearly so, and the blue and violet are present in very small quantities. In Chlorophyll, however, we have a different result: we find the extreme red of the spectrum present in almost its full intensity; the orange is nearly absent, while the yellow, greenish-yellow and green, are present in considerable amount, a small proportion of the blue and violet rays is



CHLOROPHYLL

FIG. 43.

also present (see Fig. 43). The hue of Chlorophyll presents itself to the eye as a yellowish-green, and the reason of this is due to the fact that the red and a portion of the green combine to form white light, and this, uniting with the other rays, produces a shade of yellowish-green. The fact that the Chlorophyll of green leaves reflects some of the red rays is the reason of the foliage of trees, when illuminated by the setting sun, having a reddish appearance.

The study of absorption spectra such as those above described leads to one very important conclusion: that the eye cannot distinguish the true character of any lights, white or coloured, which may be presented to it, but pronounces

them one and all monochromatic in effect, although possibly polychromatic in structure.

It is a well-known fact to painters that the appearance of a pigment depends very greatly upon the particular vehicle or medium which is used with it ; this may be noticed by an examination of drawings in crayons, water colours and oil, using the same pigment. The explanation of this phenomenon arises from the different manner in which the pigment or paint surface reflects the light that falls on it ; in the case of a crayon drawing, and to a limited extent a water colour painting, there is not only reflected the characteristic colour of the pigment, but a good deal of white light, the presence of which materially modifies the hue of the pigment as it is seen by the eye ; in the case of water colours the presence of the very small proportion of gummy matter which is employed to fix the pigments used is found to considerably reduce the quantity of white light which the pigment reflects, therefore we are much nearer to obtaining the true hue of the pigment, but there is less light reflected on the whole. When oil or varnish is used as the vehicle, the pigments appear to be much darker, the colour is richer, and there is found to be less white light reflected from the pigment. This change in appearance is due to the different conditions in which the light strikes and is reflected from the pigment. With the dry pigment, as in crayon work and chalk drawings, there is a very considerable amount of white light reflected from it, along with the characteristic colour rays, owing to the difference in the density of the air in which the light moves, and the surface from which it is reflected. In the case of water colours, or pigments immersed in water, we have other conditions, the light moving in a dense medium and reflected from a pigment which is practically only slightly more dense than itself; hence there is but little white light reflected, and the coloured light which is reflected

comes very nearly to the natural appearance of the pigment. In the case of paintings in oils we have a medium which is of the same practical density as the pigment, consequently there is very little white light reflected from it, and it will appear dark. This is particularly noticeable in the case of Prussian Blue, which, used by itself in oil, appears of a blue-black colour; and it is only when it is spread out in very thin layers on a white surface, or mixed with a white pigment, that the peculiar blue hue of Prussian Blue manifests itself. This change of colour is very noticeable with other pigments: some ochres or natural earths, which appear of a pale hue while dry, when mixed with oil appear much darker and more brilliantly tinted.

This change in appearance of pigments by the use of these media has a very important influence on their use in painting, and between the extremes of drawings in crayons and chalks and oil painting we have various intermediate qualities. In oil painting the colouring is characterised by its richness and the transparency and depth of shadows; while in crayon drawing the shades obtained are much paler, the shadows are much less intense, and there is a harshness which pervades the whole drawing.

In fresco drawing or painting the artist is very much troubled by this change of appearance of pigment due to the difference of conditions as to media, for he has to work with a wet medium, which imparts to the pigments considerable richness of colour, while the finished picture is observed when the medium has disappeared, and consequently its effects on the pigments lost, the colours will have lost much if not all of their brilliancy. The artist has perforce to be on his guard and to make allowance for this change, which renders fresco painting one of some difficulty; and few artists are successful in producing fresco drawings which are wholly satisfactory as regards harmonious colouring and uniformity of hue.

As an inference from the study of the absorption spectra such as have been described above, we may assert that coloured bodies owe their colour to a selective power they exert on the rays of light which fall upon them, quenching or absorbing some, reflecting or transmitting others; and the colour which they show depends upon the character and intensity of these latter rays.

CHAPTER III.

COLOUR PHENOMENA AND THEORIES.

Dyers, painters and all who use colouring matters of various descriptions are well aware of the fact that, using but a few of these colouring matters, they are able to produce a great variety of colour effects: thus, for instance, give the painter red, yellow and blue pigments, he can produce a great variety of other colours and tints. The same may be said of a textile colourist; for instance, by mixing a red and a yellow, orange can be produced, and by using various proportions of these two colours he can produce an infinite variety of tints of orange, from an extreme orange-red to a very yellowish-orange. Again, by mixing a blue and a yellow together, an infinite variety of green shades, from a yellowish-green to a bluish-green, may be produced; while the admixture of blue and red in various proportions will produce various tints of purple and violet; then by mixing the three colours together an infinite variety of olive, sage and brown shades, which are known to the painter as sad shades, and even black may be produced. This fact has been known to colourists for many years, and formed the foundation for that theory of three primary colours—red, yellow and blue—which from the circumstance that Dr. Brewster was the principal exponent of it, has been known as the Brewsterian theory of colours. He considers that there are three fundamental colours—red,

yellow and blue—and that by the admixture of these three colours all other colours can be produced. This theory has, however, been shown by various physicists—Thos. Young, Helmholtz, and others—to be erroneous, and it has given place to a much more correct theory, although it may be stated in its defence that it explains very well the phenomena which occur on mixing colouring matters together.

Before passing on to the consideration of theories of colours, it would be as well to consider some of the results

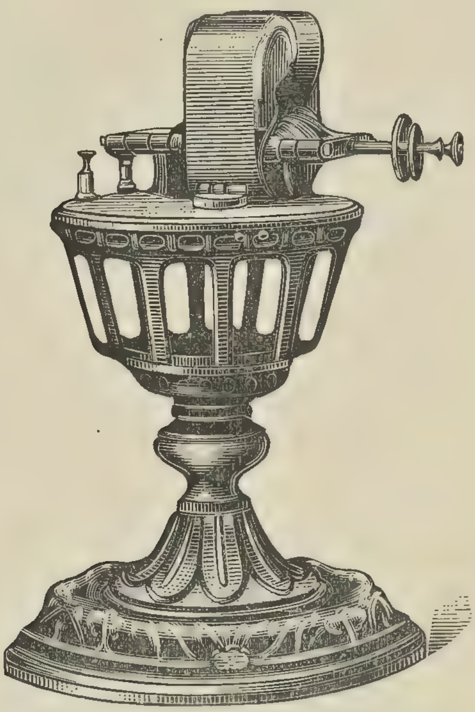


FIG. 44.

which can be obtained by mixing various colours together. In mixing colours we must carefully distinguish between the admixture of colouring matters, dyes and pigments, and the admixture of coloured lights. It will be more convenient to deal with the latter class first, and see the effects which can be produced by mixing coloured lights, and the means by which these colour mixtures can be produced.

One very common method of making such experiments in

the mixture of coloured lights is by means of a revolving disc, the plan which is used in the experiment of Newton's disc, with which every student of light is familiar. A white cardboard disc is painted with different colours along its radius (Fig. 1, Plate 2), and on rotating this rapidly, by the influence of the phenomenon known as persistence of vision, which will be fully discussed in the chapter on the physiology of light, the colours blend one into the other, and a whitish or greyish-white uniform colour is obtained.

Fig. 44 represents a very convenient rotatory apparatus, consisting of an electro-motor driven by a galvanic battery of any convenient kind. The discs of cardboard are attached to the spindle of the electro-motor, and are so arranged that

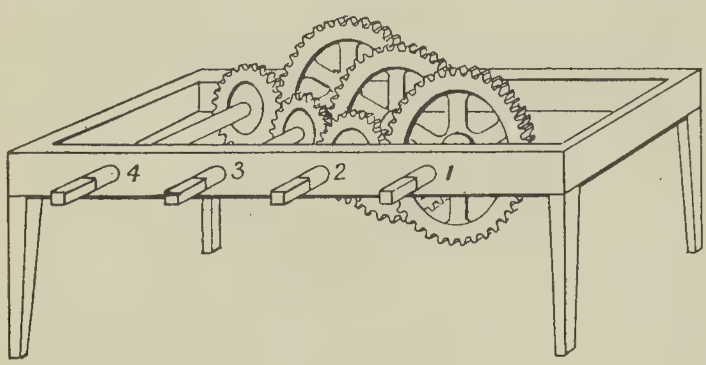


FIG. 45.

they may be changed as required. Fig. 45 is a drawing of Rothe's apparatus for rotating the colour discs. In this apparatus a variety of speeds may be obtained, from a slow to a very quick speed, by driving as may be desired, from the pulleys 1, 2 or 3: if 3 be made the driving pulley, then a slow speed is obtained; if No. 1 is used, then a quick speed is the result. If, in place of the Newton's disc, there is employed a disc painted one half blue and the other half yellow, on rotation there will be got the sensation produced by mixing blue and yellow lights together, and in this case we produce a white and not a green. The white may not, however, be quite pure, but may be more or less tinted with blue or green,

because it is extremely difficult to proportion the blue to the yellow in this method of working. A better plan is that devised by Maxwell, who takes two or more discs, each painted in any desired uniform colour; and then, by making in each a slit from the centre to the edge, he can, as shown in Fig. 46, place them together and produce a combined disc showing any desired proportions of colour; thus he can have, when using blue and yellow, either more yellow or more blue, as the results of rotating the disc show to be desirable. Fig. 47 shows the rotatory apparatus with these discs in position, and with their aid it is quite possible to study combinations with two, three, or even more colours. By changing the proportion of blue to yellow a position is reached when we obtain on

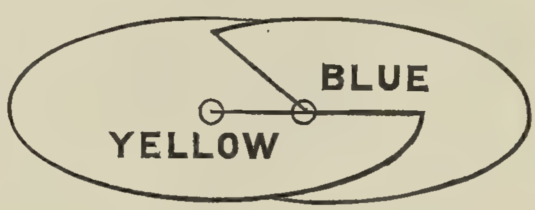


FIG. 46.

rotation a greyish-white; in no case, whatever may be the proportions of the blue and yellow, is a green obtained.

Another method of combining coloured light is to place two sheets of the desired colours side by side on the table, and then to place a sheet of glass upright between the two patches of colour; on looking through the glass at one of the patches we also see the reflection of the other, but the sensation visible to the eye is not that of the two colours separately, but the combined sensation of the two. By just changing the position of the patches it is quite possible to arrange to see them as if they overlapped, then we shall be able to see the effect of the colours being combined together as well as separately; in the case of blue and yellow patches, white is always the result of the union.

Another method of mixing colours is by means of Dove's dichroiscope, a section of which is shown in Fig. 48. This consists of a box, ABCD, with an open back, BD, in which can be placed a piece of coloured glass, and an open top, AB, on which a piece of coloured glass may also be placed; while arranged diagonally from the front to the back are a number of glass plates, CB. If now the eye be placed

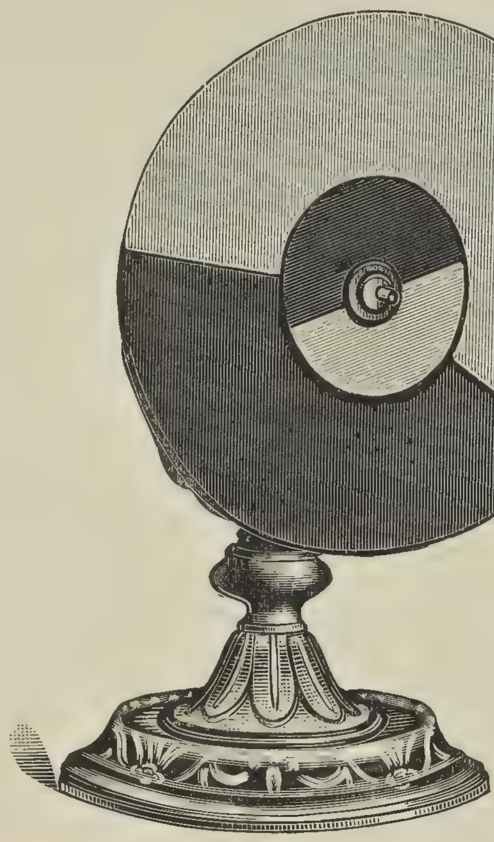


FIG. 47.

at the aperture, E, and coloured plates on the top and at the back of the box, then the light passing from the mirror, M, through the glass, BD, and direct through the glass plates, BC; if also a glass plate be placed at AB, the light which passes through this will be reflected from the surface of the plates, BC, and will also reach the eye, so that the eye receives two colour sensations, one from BD, the other from AB, but, as it is unable to distinguish the two, one colour

effect only is observable—what this colour effect is will depend upon the colours of the two glass plates; not only so, but also upon the relative proportion of the two colours. By taking advantage of the fact that the light that passes through the instrument is more or less polarised, then by observing through a Nicol's prism, P, we can adjust the relative proportions of the two colours. By rotating the Nicol's prism more or less we find that, for instance, red and green glass will infallibly give a yellow varying from orange-yellow to greenish-yellow, according to the proportions of the red and green. Blue and yellow glasses give white, green and purple give also white, red and yellow give orange, green and yellow

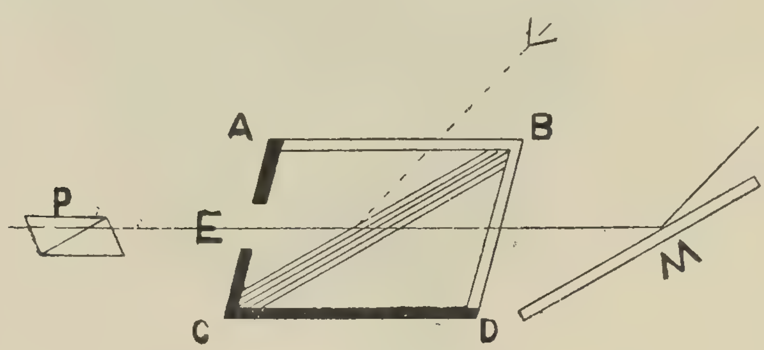


FIG. 48.

yellowish-green, and blue and red purple to violet, the tints of the mixed colour depending upon the hues of the glasses which are employed; and a little care is needed to select the glasses to give the best possible effects.

Advantage may be taken of the fact that calcspar is double refracting and therefore gives two images of an object of equal intensity; if now a small screen of cardboard has two small apertures cut in it, these apertures can be covered with pieces of stained glass, and if viewed through an achromatic prism of calcspar, two images of each glass will be obtained, four images altogether. By careful arrangement it is possible to arrange for one image of each glass to fall on the same spot, then we get the colour effect of the two colours

combined, while there are also separate images of each colour for comparison. The colour effects so obtained are the same as given by Dove's dichroiscope described above.

For showing colour phenomena on a large scale two magic lanterns may be employed, both arranged so as to be focussed on the same portion of the screen, while the use of stained glass or coloured gelatine films will give the desired results.

The following are a few results which the author has obtained in experimenting with Maxwell discs. Using ultramarine and a deep yellow disc in equal proportions, we get combinations which have a reddish hue; altering the proportion to 150 of ultramarine to 210 of deep yellow, we have a reddish-white tint produced. If, in place of using a deep yellow, we use a pale shade of yellow, then, if the proportions of the two discs are equal, a creamy-white is obtained, while if 270 parts of ultramarine and 90 parts of chrome, a pale violet tint is produced. A mixture of 180 of vermilion and 180 of ultramarine produces a lilac rose tint, while one of 270 of vermilion and 90 of ultramarine, gives a pinkish-red; or, if the proportions be reversed, 90 of vermilion and 270 of ultramarine, a blue-violet is produced. Using a mixture of 250 parts of Prussian blue and 110 of pale chrome we obtain a grey of a faint greenish tint. Using a disc of vermilion and green in about equal proportions produces a tint of a yellowish cast. In using these mixtures a great deal depends upon the depth of tone of the vermilion disc and that of the green disc, so the shade of the combined results may vary from yellowish to a pale brown. If the vermilion disc is in excess then a terra-cotta shade is obtained, while if the green disc predominates the hue becomes greenish; a combination of a vermilion disc with a yellow disc in equal proportions produces a deep orange shade, while if the vermilion predominates, an orange-red; vermilion and Prussian blue discs

in equal proportions produce a dull greenish shade—an excess of the Prussian blue produces a deep lilac, while an excess of the vermilion produces a palish red. A disc of vermilion and one of emerald green produces a whitish-yellow; this of course is the result according to Young's theory. A disc painted with violet and one painted with yellow give a yellowish-grey, while a combination of a violet disc and a dark-green disc gives a greenish-grey. A disc painted with carmine combined with one painted with green gives rise to a faint reddish tint.

As the results thus produced are due to the effect of persistence of vision, while the pigments used are not of themselves pure colours (see the spectra Figs. 30 to 42), it can never be expected that the results of these colour experiments shall be exactly those demanded by theory, but they are so within what might be termed errors of experiment. They show how wide is the difference between mixing the colour sensations themselves and mixing the pigments or colouring matters which have been used in the production of the discs; thus, a mixture of ultramarine with chrome yellow on the discs produces a reddish-white, while the same pigments mixed together produce greyish-green. Prussian blue and chrome yellow discs give a greenish-grey, a mixture of the two pigments gives a full green; vermilion and emerald-green mixed by the disc produce yellow, while in the form of pigments they give rise to a brick red. Vermilion and ultramarine mixed together by the discs give a faint rose tint, while as pigments they give rise to a purple colour.

We may also consider some of the results which are obtained by mixing coloured lights together with the Dove apparatus, with the calcite prism, and we may compare these results with the effect produced by passing light through the two glasses and observing them with the eye. Thus a red glass and a green glass observed by the prism give rise to from

a pale yellow to an orange colour according to the character of the red glass, while on looking through the two glasses placed together the colour appears from a dark-green to a black. A yellow glass and a blue glass viewed with the prism appear white, which may possibly have a pinkish hue according to the exact tone of the two glasses; by direct observation these glasses appear to be green. A mixture of red and blue glass appears of a purple or violet in the apparatus, and of a deep red directly. Yellow and red glasses appear to be yellow or orange with the prism, and of a deep orange or red seen directly. A yellow and a blue-green glass with the prism appear of a yellowish-white colour, without, of a rich yellowish-green. A violet and a green glass with the prism may have a blue colour, while without the prism they would appear to be black. From these results it will be seen that the effects obtained by mixing coloured pigments together, and those obtained by mixing coloured lights together, are of a very different kind. The difference is very marked in many cases, and one cannot be predicted from the other. Figs. 2, 3 *et seq.*, Plate 2, show some of the results which are obtained with coloured lights which are allowed to fall one upon the other on a screen from two lanterns, and the colour obtained by two coloured glasses placed together in a beam of light. In Fig. 2, Plate 3, we have the results of two discs of blue and yellow light falling upon the screen from two lanterns—where they overlap it appears white. In Fig. 3 we have the same two colours thrown together on the screen from one lantern—where they overlap it is green. These differences of result are explainable in this way: In the first case we have both blue and yellow lights illuminating the same spot, and the illumination excites in our eyes the sensation of white. In the second case the light has already passed through one glass, say the blue, and been robbed of its red and yellow rays before it passes through the yellow glass, and this again exerts

its absorbing effect and stops the passage of the blue and violet rays which reach it, and only permitting the green rays to pass through, so that green only appears on the screen. In the second case we have in Fig. 4, Plate 3, the effect of two discs of red and green light from two lanterns—where they overlap it appears yellow. This of course is in accordance with Young's theory of light. In Fig. 5, Plate 3, we see the effect of the light passed successively through the red and green glasses, the result being the production of black. This is due to the fact that the red glass, through which the light first passes, only permits of the passage of red rays, and these on reaching the green glass are absorbed, and black appears as the result.

So far we have considered the mixture of coloured sensations produced by transmission or reflection from artificial colours; it will now be as well to briefly describe the results obtained by mixing coloured lights together of a pure character, such as are got by means of either the spectroscope or the polariscope. It is quite possible to produce a spectrum by one spectroscope, and then to throw upon this any portion of a spectrum produced by another spectroscope; by an arrangement of the polariscope, as shown previously, overlapping images of two colours can be produced. Captain Abney has described an arrangement by means of three slits, which, placed in connection with the spectroscope, is capable of allowing three portions of the spectrum to fall upon the screen at one spot. The apparatus can be so arranged that any portion of the spectrum can be examined at the same time; if with such an apparatus the slit is arranged in the red, the green and the violet, we have white light produced. If now the green slit is moved towards the red the tint of the mixture becomes more reddish; and to still keep it white the slit in the red must be closed, until we find that, by having one slit on the yellowish-green and the other slit on the

PLATE V.

violet, we also are able to produce white light. This fact will tend to show that the yellowish-green rays were originally formed by the admixture of the red and the green of the original spectrum; it is also found that a mixture of red and a bluish-green produces white. In a similar manner we find that a mixture of orange and greenish-blue makes white, a mixture of yellow and blue makes white, a mixture of greenish-yellow and violet makes white, and of green and purple makes white. Putting these results in the form of a table for clearness, we have the following five combinations, any of which will produce white :—

Red and bluish-green.
Orange and greenish-blue.
Yellow and blue.
Greenish-yellow and violet.
Green and purple.

In other words, white light must contain one of these five pairs of colours, in each of which one colour is said to be complementary to the other, but these same results are obtained whether we use the spectrum lights or the lights of the polariscope. Red and green lights mixed together make yellow.

The changes which are brought about by one colour falling upon another is of very great importance, and has some bearing on the employment of pigments and dyes in the production of paintings and designs for decorative purposes. Rood has made a number of experiments on this question, and we may give his results here, with the remark that some of them have been confirmed by experiments made by the author.

TABLE I.

Yellow light falling on paper painted with

Carmine gave	Red-orange.
Vermilion gave	Bright orange-red.

Yellow light falling on paper painted with

Orange[1] gave	Bright orange-yellow.
Chrome yellow gave	Bright yellow.
Gamboge gave	Bright yellow.
Yellowish-green[2] gave	Yellow.
Green[3] gave	Bright yellow-green.
Blue-green[4] gave	Yellow-green (whitish).
Cyan blue[5] gave	Yellow-green.
Prussian blue gave	Bright green.
Ultramarine blue gave	White.
Violet[6] gave	Pale reddish tint.
Purple[7] violet gave	Orange (whitish).
Purple[8] gave	Orange.
Black[9] gave	Yellow.

TABLE II.

Red light falling on paper painted with

Carmine gave	Red.
Vermilion gave	Bright red.
Orange gave	Red-orange and scarlet.
Chrome yellow gave	Orange.
Gamboge gave	Orange.
Yellowish-green gave	Yellow and orange.
Green gave	Yellow and orange (whitish).
Blue-green gave	Nearly white.
Cyan blue gave	Grey.
Prussian blue gave	Red-purple or blue-violet.
Ultramarine blue gave	Red-purple or blue-violet.
Violet gave	Red-purple.
Purple violet gave	Red-purple.
Purple gave	Purple-red or red.
Black gave	Dark red.

TABLE III.

Green light falling on paper painted with

Carmine gave	Dull yellow.
Vermilion gave	Dull yellow or greenish-yellow.
Orange gave	Yellow and greenish-yellow.
Chrome yellow gave	Yellowish-green.
Gamboge gave	Yellowish-green.

[1] Mixture of red lead and Indian yellow.
[2] Mixture of gamboge and Prussian blue.
[3] Mixture of emerald green with a little chrome yellow.
[4] Mixture of emerald green with a little cobalt blue.
[5] Mixture of cobalt blue and emerald green.
[6] Hoffmann's violet BB. [7] Hoffmann's violet BB and carmine.
[8] Hoffmann's violet BB and carmine. [9] Lamp black.

Green light falling on paper painted with

Yellowish-green gave	Yellowish-green.
Green gave	Bright green.
Blue-green gave	Green.
Cyan blue gave	Blue-green.
Prussian blue gave	Blue-green, cyan blue.
Ultramarine blue gave	Cyan blue, blue.
Violet gave	Cyan blue, blue, violet-blue.
Purple violet gave	Pale blue-green, pale blue.
Purple gave	Greenish-grey, grey, reddish-blue.
Black gave	Dark green.

TABLE IV.

Blue light falling on paper painted with

Carmine gave	Purple.
Vermilion gave	Red-purple.
Orange gave	Whitish-purple.
Chrome yellow gave	Yellowish-grey, greenish-grey.
Gamboge gave	Blue-grey.
Green gave	Blue-green, cyan blue.
Blue-green gave	Blue, cyan blue.
Cyan blue gave	Blue.
Prussian blue gave	Blue.
Ultramarine blue gave	Blue.
Violet gave	Ultramarine, violet-blue.
Purple violet gave	Blue-violet.
Purple gave	Violet-blue, purple-violet.
Black gave	Dark blue.

Incidentally there has been mentioned some of the colour shades which can be produced by the admixture of various pigments together. It will be as well if we devote more attention to this question and also to the colours or shades obtained by the dyer in mixing various dye-stuffs together. For instance, when chrome yellow and vermilion are mixed an orange is produced; when a yellow pigment and a blue pigment are mixed together a green is the result—as, for instance, mixing Prussian blue and gamboge, a very favourite mixture with artists; or Prussian blue with chrome yellow, which forms the Brunswick green of the house painter. The reason of these two pigments producing green and not white, as would have been the case with blue and green lights, is

due to the fact that Prussian blue reflects green light as well as blue light, as is seen from its spectrum given on page 50, while the chrome yellow, as will be seen from its spectrum given on page 67, also reflects green as well as yellow.

It is usually stated, in explaining this effect, that the blue rays of the one pigment and the yellow rays of the other pigment neutralise one another, allowing only the green rays to develop themselves, but it is really because the combined absorptive action of the pigments on the light results in only the green rays being allowed to pass or reflect that the mixture of yellow and blue pigments produces green. When red and yellow pigments are mixed together, orange is the result, as stated above; in this case a somewhat different explanation is required, inasmuch as we not only get an absorption effect of the two pigments on the light, the red absorbing all the rays from the violet to the green, and most of the yellow; the yellow pigment absorbing all the rays from the violet to the bluish-green, and most of the red—thus orange itself, and part of the red and part of the yellow are the only rays not absorbed, and hence reflected to the eye; also the combined effect of red rays and yellow rays upon the eye is to produce orange, and hence it is that the red rays and the yellow rays, which both pigments allow to pass, also help in the production of orange.

Again, when blue and red pigments are combined together, violet is the result; here again, as with the orange combination, we have not only the absorptive effect of the two pigments on the light, but also the physiological effect, inasmuch as when red and blue rays are both present they give rise to the sensation of violet in the eye.

But the character of the orange, green or violet which is produced largely depends upon the character of the red, yellow and blue pigments which are used, and upon the relative proportions of them which are present. Ultramarine,

although a blue pigment, does not give as good greens as Prussian blue; its tone approaches more nearly to a pure blue than does that of Prussian blue, and it does not reflect as many of the green rays as does the latter pigment (see Figs. 39 and 42). Yellow ochre, again, does not produce good greens, but greyish tones. Carmine produces purer violets with Prussian blue than does vermilion, because it reflects more of the violet rays than the latter pigment, as will be seen by a comparison of the spectra given in Figs. 30 and 31.

If a red pigment and a green pigment are mixed together, a brown is the result, the brown varying in tone or hue according to the relative proportions of the two pigments; thus brown is really a resultant of a double effect first with the red and the green tending to absorb nearly the whole of the rays, and only permitting the red, orange and yellow to pass, while there is a considerable decrease in the luminosity of the mixture, which exhibits itself to the eye by giving a brown appearance to it. Mixing an orange and a green pigment has a similar effect, only the mixture is not so dark.

The dyer, like the painter, produces a great many of his effects by mixing various dye-stuffs together. Thus he gets brown by mixing a red, a yellow and a blue dye together, and by varying the proportions he can produce a great range of shades. By using Archil, Turmeric and Indigo extract he gets a brown, and a similar brown is got from Indian yellow, Aniline blue, and Orange 2; it is to be noted that the orange or yellow predominates in each case—by increasing the proportion of the blue, the brown becomes darker. The dyer is also accustomed to produce greys by mixing a red, a blue, and a yellow dye, as for instance a grey from Chromotrop 2R, Cyanine B, and Azo yellow. A spectroscopic examination of this mixture would show that between them they absorb all the rays, for each so acts as to take out its own

proportion of the rays, and therefore black results; this, mingling with the white of the fabric, produces a grey effect. By increasing the proportion of the red, reddish-greys are obtained, while if the blue is increased, then bluish-greys are the result, or if both the blue and the yellow are increased, then a greenish-grey is obtained. Like the painter, the dyer gets his greens by mixing blue and yellow dyes together in various proportions, and occasionally he adds a little red for such colours as peacock green; thus, by using a mixture of Cotton blue and Acid yellow and Chromotrop, a peacock green can be dyed. Many of the modern coal-tar blacks have a bluish or violet shade; it is found, by using a little yellow or green dye, that the black is changed and becomes much purer. There is no doubt that this is due to the fact that the addition of this yellow or green dye results in the absorption of the blue which the original dye-stuff allowed to pass through. Black can be dyed on wool by using a mixture of Naphthol blue, Indian yellow and Naphthol green: this black is produced as the result of each of these dyes absorbing the whole of the spectrum, and in allowing no rays to be reflected or transmitted. It is of course impossible to describe or to notice all the colour effects which may be obtained or produced by the admixture of different colouring matters, but it may be stated here that much of the effects of such dark shades as browns, olive-greens, etc., is due to their low reflecting power for light, for in the case of light tints such as greys, lilacs, pinks, creams, we have the fibre, or rather the light reflected from it, also playing a part in the sensation developed in the eye. We shall have further to consider the effects brought about by changing the luminosity of light either by an increase or a decrease thereof.

The same tint may often be produced by combining different dye-stuffs together; thus, for instance, a bright green may be got with indigo extract and Naphthol yellow,

and also by using Naphthol yellow, Orange G and Acid green, but it does not follow that, while the tint of the two colours may be the same, they have quite identical properties; when they are subjected to various illuminations they may show slight differences of tints, and again the addition of other colouring matters may produce divergent effects; thus, while the addition of a red dye-stuff to one of the mixtures may produce a deep brown, with the other it may form a maroon. Again, the shade of blue produced on wool by indigo extract may be matched by daylight with a mixture of Naphthol yellow, Violet 4B, and Cyanol, but viewed by gaslight the shades are quite different. The addition of a crimson dye to the indigo may convert it into a bluish-black, while the same addition to the mixture may produce reddish-black. These differences in effect are due to differences in the absorptive action of the colouring matters on the light—the eye, as it were, sees the mean of the rays of light which are transmitted or reflected, and it has no power of distinguishing what particular groups of rays are actually present, yet the character of the shades which may be produced by the admixture of various dye-stuffs together always depends upon the character of the rays which those dye-stuffs transmit or reflect, and not upon what is seen by the eye. It may be broadly stated that when dye-stuffs are mixed together whose absorption spectra more or less overlap one another, then it is the overlapping portion which governs the shades which are produced. The larger this portion is, the brighter and more luminous will be the hue of the colour as visible to the eye; the smaller the overlapping portions are the less luminous and duller will appear the shades. When dye-stuffs are used whose spectra do not overlap one another, then black will invariably ensue.

We may now devote some attention to the subjects of primary and complementary colours. It has been pointed

out that the fact of the painter being able, by using red, blue and yellow pigments, to produce all colour effects, has led to the development of the Brewsterian theory of there being three primary colours—red, yellow and blue. As this theory has a good many practical applications we will devote some attention to it. By the combination of two of these primary colours we get, as has already been described, a series of three other colours, which are known as secondary colours, these being orange, green and violet—the orange

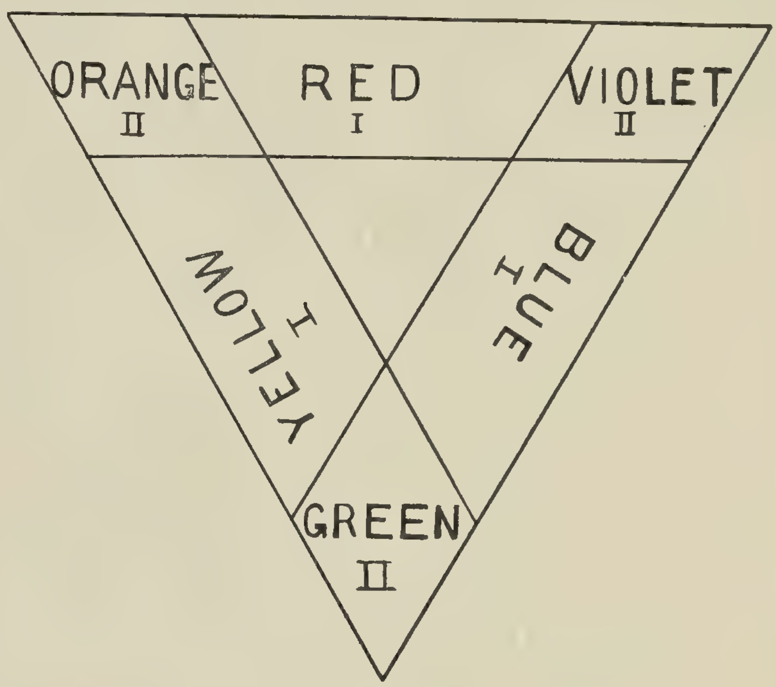


Fig. 49.

from the combination of the red and yellow; the green from the combination of the yellow and blue; and the purple or violet from a combination of the red and blue. Then by the combination of these secondary colours together in pairs or with a primary colour, we get a series of other colours which are called tertiary colours. Coloured diagrams on Plate 4, and also Figs. 49 and 50, illustrate this theory of primary, secondary and tertiary colours. The diagrams take the form of triangles, the sides of which are filled with a primary or secondary colour overlapping at the corners; the central

portion is also filled with each colour, and therefore is produced by the union of the three colours forming the plate. In the triangle in Fig. 49 are employed the three primary colours—at the top red, left-hand side yellow, and the right-hand side blue; the red and yellow overlap at the top left-hand corner and form the secondary colour orange, similarly the red and blue overlapping in the top right-hand corner form the secondary colour violet, and the blue and yellow where they overlap at the bottom corner form green, while in the middle is a tertiary colour formed by the union of the three primary colours formed in constructing this diagram. In

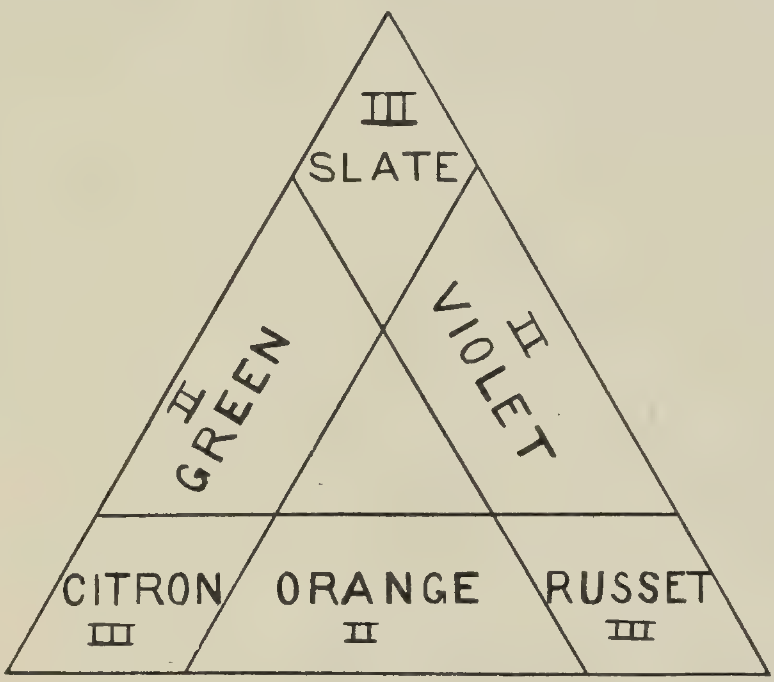


Fig. 50.

Fig. 50 we have the triangle formed from the three secondary colours; at the left-hand side is green, right-hand side violet, bottom side orange; where the green and the violet overlap at the top corner we have the tertiary colour commonly named slate; at the left-hand bottom corner we have the green and orange overlapping and we get the tertiary colour named citrine; while at the right-hand bottom corner we have the violet and green overlapping and forming the

tertiary colour usually named russet. In the centre is a more complex colour formed by the union of the three secondary colours. The diagrams (Figs. 49 and 50) should be compared with the corresponding coloured diagrams on Plate 4. The combination between the primary and secondary colours to form the tertiary colours may take place in a great variety of ways, and consequently there can be produced a large number of shades of tertiary colours depending upon the relative proportions of the constituent colours from which they are formed.

The tone, tint, or shade of a colour are terms which are frequently met with in colour work, and are somewhat indefinite in their application, and are used by colourists rather indiscriminately. If a colour is mixed with a white pigment we weaken or reduce its tone, and by using various proportions of the two (the colour and the white) we can get quite a range of tints, as they are called. By mixing black with the pigment we produce darkish-red sand shades, as they are called. Here we have quite a scale or range of shades according to the relative proportions of the black and the pigment; we can therefore distinguish the last two classes of the colours.

First, a reduced scale of tints made by mixing the colour with white.

And second, a darkened scale of shades which are produced by mixing the colour with black.

The tertiary colours are always more or less dull, on account of the fact that a mixture of the three primary colours should produce black, but in the tertiary colours one or other of these three primary colours has predominated, and it is this predominating colour which produces the hue of the tertiary colour.

It has been found, in mixing the primary colours, that the best effects are not obtained by mixing the pigments employed in equal weights, but rather in what may be called equivalent

proportions: thus, it has been found that three parts of yellow require five parts of red to make a good orange; in the same way it has been found that three parts of yellow require eight parts of blue to form a green, and that these eight parts of blue are able to combine with five parts of red to form a violet. These numbers three, five and eight are considered to be the equivalents of yellow, red and blue respectively; but too much stress must not be laid on these colour equivalents, for they will vary with the particular pigments which may be used; however, they will serve a convenient purpose occasionally. By following the proportions of red and yellow, and yellow and blue, or of blue and red, we can produce a variety of tints of the secondary colours: these we may represent in the following manner, using the letters R, Y and B for the three primary colours :—

Y + R = Orange.
2Y + R = Yellowish-orange.
Y + 2R = Reddish-orange.
R + B = Violet.
2R + B = Reddish-violet.
R + 2B = Bluish-violet.
B + Y = Green.
2B + Y = Bluish-green.
B + 2Y = Yellowish-green.

COMPLEMENTARY COLOURS.

It has been shown that when two coloured lights are mixed together white light is produced. This statement is only true of a number of combinations, such as blue and yellow, and green and purple (see page 65); such pairs of colours are said to be complementary to one another. We find that a knowledge of pairs of complementary colours is of considerable importance from an artistic point of view, inasmuch as the colours thus paired appear of the greatest possible contrast to one another, while at the same time they harmonise more together than any other combinations would do—as,

for instance, a red design on a green ground shows up much more distinctly and is much more harmonious than a red on blue or a red on violet. Similarly a yellow design on a blue ground shows up much more strongly than a yellow design on a green ground.

All the spectrum colours are primary, and each of them has its own particular complementary colour situated in some other portion of the spectrum. We may give here a table of the complementary colours of the principal divisions of the spectrum:—

TABLE OF COMPLEMENTARY COLOURS.

Red	Bluish-green.
Orange	Deep-blue.
Yellow	Ultramarine blue.
Greenish-yellow	Violet.
Green	Reddish-violet.

Many other pairs could be formed. The colours which lie between the red and the orange have their complementary colours between the bluish-green and cyan blue. The colours which lie between yellow and green find their complementary colours in the portion lying between the ultramarine blue and the reddish-violet.

The best plan of studying the production of complementary colours is by means of the polariscope arranged to produce, by means of selenite plates of varying thickness, discs of colour such as those shown in Figs. 5 to 8 on Plate 2. It is the best way of producing complementary colours, and gives by far the most satisfactory results. It is impossible in words to convey any idea of the exact shade of the pairs of colours which are complementary to one another. It is not always easy to match them by painting, but the latter method is by far the most satisfactory.

The polariscope will not, however, give us the complementary colours of many tints which are produced by a

pigment, and of which it is desired sometimes to know the complementary colours. This is especially the case with olive-green, brown, and other tints of a like character. This is caused by the fact that the colours, as obtained by the polariscope from selenite, are very largely mixed with white light, which considerably increases their luminosity, whereas the colours referred to have a very weak luminosity. We can get a solution of this problem by means of the Maxwell discs, if we take advantage of the fact that the rotation of

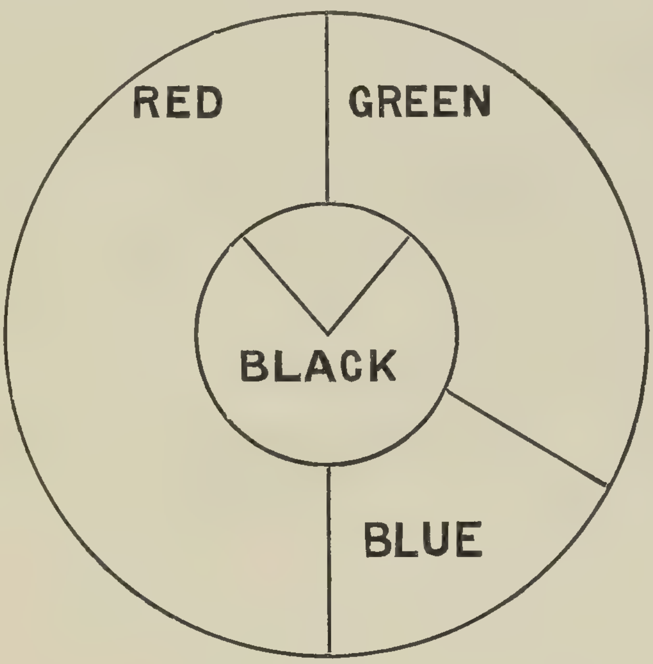


Fig. 51.

two primary colours tends to produce a grey, and if we take one colour which we require to match, and by employing one or two other discs, arranged so that with the other primary colours they will produce a grey—such a combination is shown in Fig. 51, where we have a combination of three large discs—one red, one green, the other blue; and two small discs—one black and one white. The black and white by rotating give the sensation of grey, the red is the colour which is desired to match, and by mixing the green and blue in certain proportions and rotating the discs we get a grey

matching that of the central discs: the combination of the green and blue is therefore complementary to the red. Again, Fig. 52 shows the manner of producing a complementary colour to a yellow ochre; the yellow required more blue than green to obtain a grey identical to that produced by the rotation of the black and white discs. Even this method is not altogether satisfactory, for the relative intensities and luminosities of the pigment used in the production of the discs have a very considerable influence in modifying the

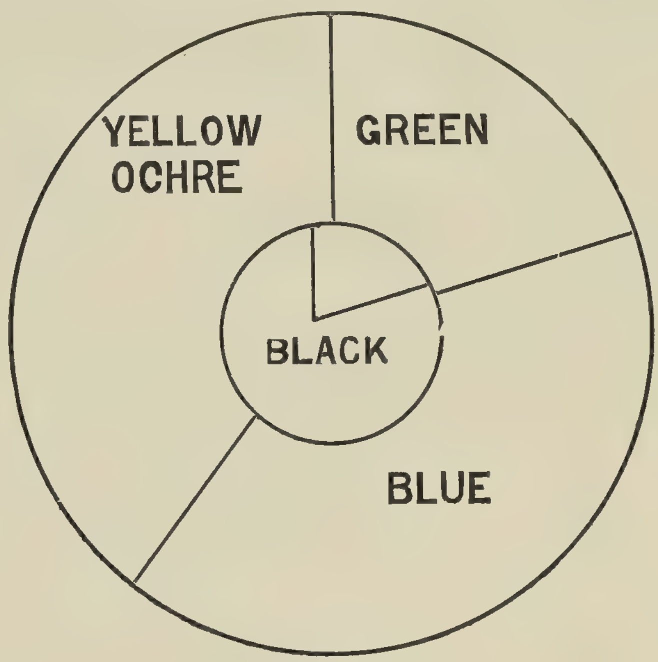


Fig. 52.

results. We can of course only obtain the true complement of any colour if we combine it with other colours of an equal degree of intensity and luminosity. Unfortunately this is not always the case, as the red and yellow pigments—carmine, vermilion, chrome yellow—are much more luminous than the pigments—emerald green, cobalt blue, ultramarine—which we have to employ in this method of experimenting on producing the complementary colours.

In painting, and according to the Brewsterian theory of

colour, the term complementary is employed in another sense. According to this theory there are three primary colours—red, blue and yellow. Now by mixing any of these three together we can get three other colours, orange from the yellow and red, green from the yellow and blue, and purple or violet from the red and the blue. These are called secondary colours, and each secondary colour is considered to be complementary to the third primary colour which is not used in producing it; thus, green is complementary to red, blue to orange, yellow to violet. This is shown in the coloured chart Fig. 5, Plate 4, which shows a triangle the three sides of which are occupied by the three primary colours, while at the points the colours overlap and form the secondary colours. The primary on one side is complementary to the secondary in the corner opposite to it. In the coloured triangle No. 6, Plate 4, are shown in a similar way the secondary colours, orange, green and violet, with at the corners the tertiary colours they form, the latter being complementary to the secondary to which it is opposite, slate to orange, citron to violet, russet to green.

SUPPLEMENTARY COLOURS.

This is a term which will be found in some text-books, and indicates the other colour which is left when two of the primary colours are taken from any combination. This is a term which is extremely vague in its derivation and use.

Colour Theories.—Having discussed many if not all the phenomena of colour production and admixture it will now be convenient to consider some of the theories which have been propounded from time to time to account for these phenomena.

Brewster Theory.—This theory has already been several times referred to in speaking of primary and secondary colours,

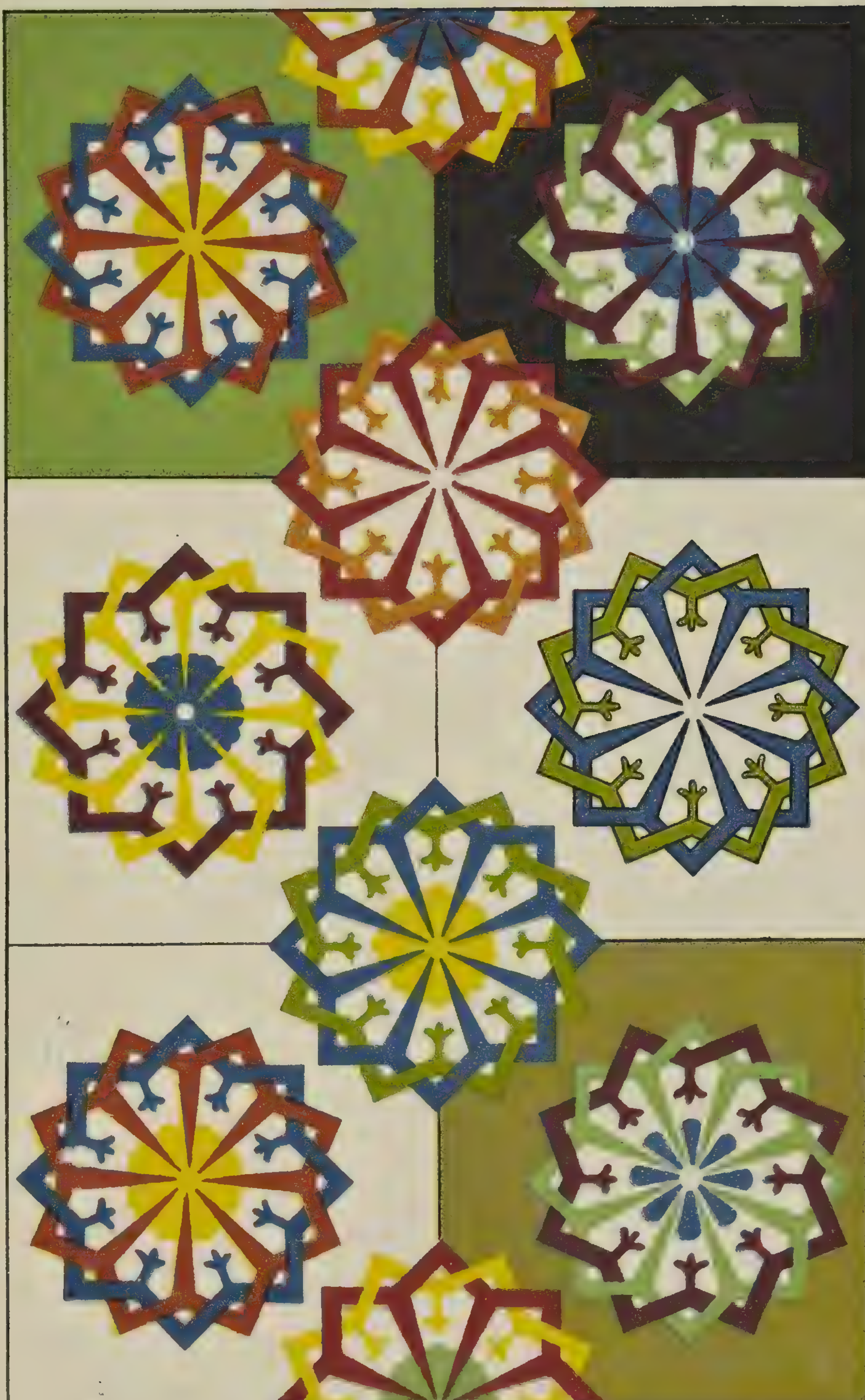
and its bearings have been adequately discussed. The red, blue and yellow primary theory fails, however, to account for all the colour phenomena which can be produced, chiefly because it was not based on a proper examination of the true composition of coloured lights.

Young-Helmholtz Theory.—Thomas Young was the first to note that the Brewster theory did not explain the results which can be obtained by mixing the spectral colours together, nor the effects which can be got by means of the revolving Maxwell discs. He then propounded a theory of three primary colours consisting of red, green and blue; this theory has been more fully developed by Helmholtz, and hence is known as the Young-Helmholtz theory, and, as it explains in a fairly satisfactory manner all colour phenomena, it has become almost universally accepted by colourists.

According to this theory there are three primary colours—red, green and blue. Now as there are various hues of these colours, some difference of opinion exists amongst colourists as to the exact hue which should be adopted as the true primary colour, particularly as regards the blue. The primary red is usually accepted to be one having much the same hue as carmine or a mixture of equal proportions of carmine and vermilion, the green resembling emerald-green in hue, being perhaps a little deeper in tone, the blue approaching the tone of Prussian blue. Some colourists are inclined to regard the true primary blue as being a little greener in tone than Prussian blue, while others, Maxwell and Müller, consider the primary blue as one having a more violet hue, like ultramarine.

When two of these primary colours are mixed together secondary colours are obtained; thus red and green yield yellow, green and blue give a greenish-blue, named sea green, while red and blue give a kind of purple tint. It will be observed that in thus mixing the colours we get the tint

PLATE VI.



which is intermediate between them in the position they occupy in the spectrum. When more than two of the primary colours are mixed together we get white light. We would point out that the results which are here stated to be obtained are those which may be got with spectral colours or the colours obtained with the polariscope, or in some cases with coloured lights thrown from several sources on a screen (see Plates No. 2, Figs. 2 to 5, and No. 3, Figs. 5 to 8). If we arrange three magic lanterns to form three overlapping discs on the screen, and in one have a red glass, in the second a green glass, and in the third a blue glass, it will be found that where the red and green overlap yellow is obtained, where the red and blue overlap then violet is got, and where the blue and green overlap a greenish-blue is got, while in the centre will appear a triangular white space where all three of the colours overlap.

To obtain the best results, care will have to be taken in selecting the red, blue and green glasses so that they are of the right hue, and probably many will have to be tried before the right ones are obtained.

We have here one of the fundamental differences between the old and the new theories. In the old theory, based as it is upon the admixture of pigments, the addition of the three primary colours together gives rise to the production of another tertiary colour; while in the newer theory we have white produced, which is not only true in theory but in fact, for we have seen that white light is built up of coloured lights, and theories ought to explain facts.

If, instead of adding coloured lights together to form white light, we take away one of the primary colours from white light, there will be left, according to the Young-Helmholtz theory, a combination of the other two primaries: thus, if we take away blue there will be left yellow, which is produced by the combination of the other primaries red and green; if the red be

next taken away we shall have green left; and if this be taken away we shall have no light at all; in other words, blackness results. It is thus seen that black denotes the absence of colour. Now as it has been shown that the colour of bodies is due to their possessing an absorptive action on the light which falls upon them, a black body is black because it absorbs all the light which falls on it.

According to the Young-Helmholtz theory the colour effects which are obtained by mixing pigments, dyes and colouring matters together are due to the absorptive action of the colouring matters upon the light which falls upon them. This absorptive action can only result in one thing, and that is a reduction in the intensity of the light, and so the colour which is produced by the mixture of two or three other colours will be weaker as regards its light intensity and therefore appear duller or darker; in the end, by total absorption of all the light, black will result. How soon this happens will depend entirely upon the colouring matters which are used; in some cases—as, for instance, when the dyer uses Azorubine and Acid Green—two will suffice, in other cases three or more may be required.

If the colouring matters are so mixed together that, while there is some considerable reduction in the intensity of the light, the colours are such as would form an orange—that is, red and yellow predominate—then brown will result; if, on the other hand, the green is predominant the resulting colour will have an olive hue, while plum shades will result when the red and blue predominate.

In a similar manner we may account for the production of all the secondary and tertiary hues produced by the admixture of pigments and colouring matters together. If there is an absorption of light which tends to produce the same effect as adding black, then the predominant colours show themselves somewhat in the manner indicated above.

Maxwell's Theory.—This closely resembles that of Young and Helmholtz, only differing from it as to the hue of the primary colours. Maxwell takes scarlet, green and a violet tone of blue like ultramarine as the primary colours, the wave lengths corresponding to the true primaries being in millionths of an inch, for the scarlet 2328 between lines B and C, for the green 1914 near line E, for the blue 1717 near line G. As regards the secondary colours obtained on mixing the primaries together and the relationship of primary and complementary colours, Maxwell agrees in all essential particulars with Helmholtz. In 1861 Maxwell demonstrated the correctness of this theory in lectures at the Royal Institution.

A solution of sulphocyanide of iron matches well the primary red, one of chloride of copper the primary green, and one of ammoniacal sulphate of copper the primary blue. With three lanterns, and using troughs filled with these solutions, many experiments on the mixture of the primary colours may be made.

Colour Photography.—It may be of interest here to refer to the production of photographs of objects in their natural colours, particularly as it bears on the theory of colour. While, so far, all attempts to produce a permanent photograph of objects in their natural colours have not been successful, yet transient coloured photographs have been produced. Henry Collen, in 1865, was one of the first to lay down the lines on which successful colour photography might possibly be carried on, although he himself did no work in this direction. He described his ideas thus :—

Obtain a negative sensitive to the blue rays only, obtain a second negative equally sensitive to the red rays only, and a third sensitive to the yellow rays only.

There will thus have been three plates obtained for printing in colours, each plate having extracted all its own peculiar

colour from every part of the subject in which it has been combined with tones used in chromo-lithography. Now it is evident that if a surface be prepared for a positive picture, sensitive to yellow rays only, and if the two negatives, sensitive only to blue and red, be superimposed one on the other, and be laid on this surface, the action of light will be to give all the yellow existing on the subject; and if this process be repeated on other surfaces, sensitive only to red or blue respectively, there will have been produced three pictures of a coloured object, each of which contains a primitive colour from that object.

Now, supposing the first great point achieved, *viz.*, the discovery of substances or preparations, each having sensitiveness to each of the primary colours only, it will not be difficult to imagine that the negatives being received on the surface of a material quite transparent and extremely thin, and that being so obtained, are used as above, *i.e.*, one pair of superimposed negatives to obtain the colour of the third, three positives will be obtained, each representing a considerable portion of the form of the object, but only one primary of the decomposed colour of it. Now, if these three positives be received on the same kind of material as that used for the negatives, and be then laid the one on the other, with true coincidence as to the form, and all laid upon a white surface, it will not be difficult to imagine that the effect would be not only the representation of the form of the object, but that of its colour also in all its variations.

Very perfect contrivances would be required to produce the superposition of both negatives and positives, and a considerable difficulty would exist in handling the extremely thin material. This, however, as well as other difficulties, will easily be overcome when the chemist has discovered the three preparations, which are each of them sensitive to one of the primary colours only.

Mr. F. E. Ives, of Philadelphia, has succeeded in devising two instruments—the Photochromoscope and Kromskop—by means of which it is possible to produce and observe photographs in colours.

The process, to be brief, consists of making three negatives on colour-sensitive plates, which are exposed simultaneously in a triple camera, behind light filters that are carefully adjusted to transmit to each plate just the kind and amount of light that will cause the resulting negative to make a coloured picture, which, when combined with the other two coloured pictures produced in the same manner, will counterfeit the colours of the spectrum, or the colours and light and shade of any object. In order to accomplish this, each spectrum colour that is not counterfeited by any one reproduction colour must, of course, be represented by the two negatives in such a manner as will secure a definite and suitable combination of two reproduction colours in the final result. Negatives of the required character are made by exposing a cyanine-stained gelatino-bromide plate through a double screen of chrysoidine orange and aniline yellow of suitable intensity; for the red sensation, a cyanine-erythrosine gelatino-bromide plate through a screen of aniline yellow of suitable intensity, and for the green sensation an ordinary gelatino-bromide plate through a double screen of chrysophenine yellow and R.R. methyl violet. The sensitive plates are, of course, exposed simultaneously in a triple camera of special design.

The Photochromoscope consists essentially of a box, open at both ends, with three coloured glasses or screens (red, green and blue-violet) and three pairs of small mirrors arranged within it. With such a simple device it is possible to view the monochromatic triple image of the chromogram as a single image reproducing all the colours of the object photographed; but in order to magnify the image, to

improve the illumination, and in other respects to add to the efficiency and convenience of the instrument, it is constructed upon a more elaborate plan, with condensing lenses, colour screens, mirrors, objective lens, focussing eye-piece, etc.

THE KROMSKOP.

This instrument consists of a case with five pieces of coloured glass, a reflector and eye-lenses, which are so disposed as to blend the images, either single or stereoscopic, and focus them upon the retina.

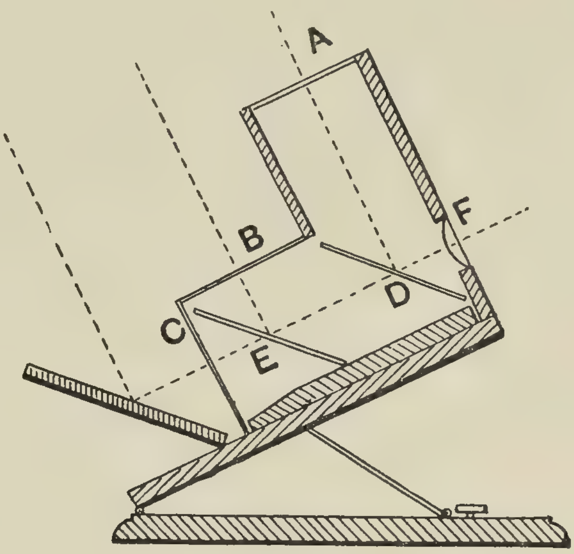


FIG. 53.

The construction and operation of the Kromskop may be readily shown by reference to a diagram (Fig. 53). A, B and C are red, blue and green glasses, against which the corresponding images of the colour record are placed when the instrument is in use.

D and E are transparent reflectors of coloured glass. F represents the eye-lenses for magnifying the image. Beyond C is a reflector for illuminating the images at C, those at A and B being illuminated by direct light from above.

The operation of the Kromskop is as follows: The green images are seen directly, in their position at C, through

the transparent glasses D and E. The blue images are seen by reflection from the surface of the glass, D, and also appear to form part of the images at C. In the same way the red images are seen by reflection from the surface of the glass, E, and also appear to form part of the image at C. And finally the eye-lenses at F not only magnify but cause the eyes to blend the two images which constitute the complete stereoscopic pair, as in the ordinary stereoscope. The result is a single image, in solid relief and in the natural colours.

Hering's Theory.—Hering has proposed a theory of six primary colours arranged in three pairs, black and white, red and green, and blue and yellow, connecting these three pairs with three corresponding sets of nerves in the eye.

The physiological bearing of these various colour theories will be described in the chapter on the physiology of light.

CHAPTER IV.

THE PHYSIOLOGY OF LIGHT.

THE sense organ by means of which we perceive the phenomena of light and colour is the eye, of which man has two, situated in the upper portion of the face, and are each similarly situated. The eye is a globular ball loosely placed in a cavity known as the orbit, its movements being controlled by a number of muscles; the eye and the orbit are shown in Fig. 54. A section of the eye is given in Fig. 55, where it is seen to be a hollow ball formed of a very dense

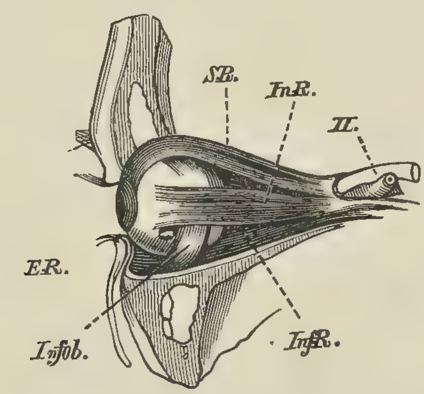


FIG. 54.

and muscular tissue, the front portion of which is transparent, while by far the largest portion is opaque. The transparent portion is known as the cornea, shown at *Cn* in the figure. The opaque portion is called the sclerotic, and is shown in the figure at *Scl*. The interior is divided into two cavities, a small anterior cavity at *Aq* next to the cornea, and a posterior cavity, *Vt*, by means of a transparent crystal

structure *Cry*, the function of which is to act as a lens on the light which passes through the cornea. In front of the lens is a kind of diaphragm, *Ir*, known as the iris, in the centre of which is a circular hole, the pupil, the main use of which is to simply allow the light to pass through the central portion, which is the most useful portion of the lens. The anterior cavity, *Aq*, is filled with what is known as the aqueous humour, while the posterior cavity is filled with a fluid substance known as the vitreous humour. In close

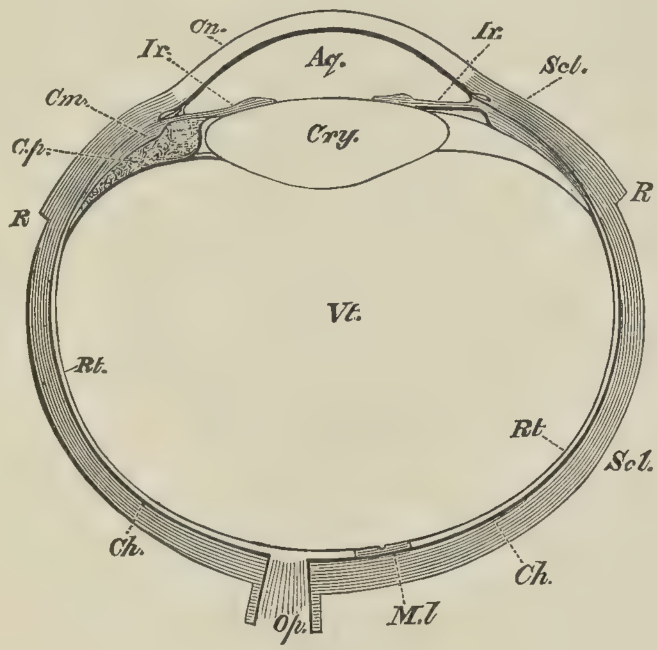
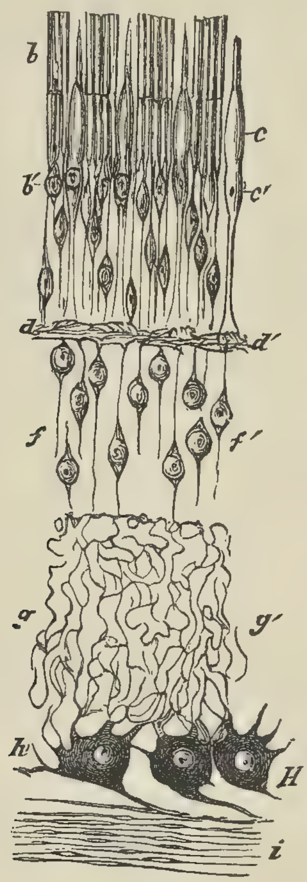


FIG. 55.

contact with the sclerotic is a muscular member which, on account of its containing polygonal cells and pigmentary matter, is known as the choroid, marked *Ch* in the drawing; this choroid coat goes all round the interior of the eye, and in front it is attached to the muscles of the lens by ciliary processes. Immediately in front of this coat is another highly important one, the retina, marked *Rt* in the drawing. This retina is a highly nervous structure, and plays an important part in the observation of light. The retina is in

connection with the optic nerve and is a continuation thereof, as is shown in the drawing where *Op* represents the optic nerve.

Fig. 56 is a vertical section of the human retina as seen under the microscope. There is first of all at *i* next to the sclerotic what is known as the anterior limiting membrane, while next to this is a layer of nerve fibres which separate



A
Fig. 56.

themselves up into the small fibres, passing through the substance of the retina. Upon this at *hH* is a layer of nerve cells; again above these is a mass of granular tissue, the granular layer as it is called, and a small layer is at *gg'*, while between these two occurs what is known as the anterior nuclear layer, a small layer; the exterior layer is at *dd'*. At *bc* is what is known as the external limiting membrane,

which allows the nerve fibres to pass through to the undermost portion of the retina. This consists of a layer, *b*, of rods and cones as they are called. It is in this layer of rods or cones that the nerve sense or light is supposed to reside. The retina is uniformly distributed over the surface of the eye except at two places, one in the middle and in the line of vision, where there is a slight depression of a yellowish hue, this is known as the "yellow spot," or the macula lutea, and the blind spot, which on the under side has a radial appearance, caused by the entrance of the optic nerve, and this spreading over the retina from that point as a centre.

At the yellow spot the rods are absent, the fibres are fewer in number, only the cones being present, while the yellow colour is due to a small deposit of pigmentary matter.

Persistence of Vision.—When an image of an object is formed upon the retina it remains there for a perceptible period of time. This duration of the impression on the retina is the cause of many illusive phenomena being observed by the eye. Thus if a black disc be fitted to the rotatory apparatus shown in Fig. 44, and on this disc is placed a small patch of white and the disc rotated, we observe, not a patch of white on black, but a grey ring which does not vary in intensity with any rapidity of rotation. The tint of the grey which is produced depends upon the proportion between the patch of white and the amount of black at the particular distance from the centre of the disc; if the white patch be made larger then the grey will be lighter, but if the patch be smaller then it will be darker. If a disc be so arranged that one half of it is black, and the other half white, then the grey which is produced by the rotation of the disc has half the luminosity of white light. That this is so can be proved experimentally in the following manner: A prism of calcspar will produce two images of a strip of white paper; each of these images is just one half or nearly one half the luminosity

of the original. Now if the grey produced by the rotation of the black and white disc be compared as regards luminosity with the images formed by the calcspar, they will be seen to be practically the same.

Grey may be produced by the rotation of a disc which contains alternate black and white spots. The intensity of the grey is changed by an alteration in the speed of rotation and it is quite independent of the absolute duration of the periods of light and dark. This can be shown by the employment of

FIG. 57.

the disc shown in Fig. 57, in which the disposition of the black and white portions is such as to produce variations in the proportions or duration of light and dark as the disc rotates. If this disc be rotated at a speed of twenty revolutions per second, then the periods in which these alterations of light and dark exist are, for the inner zone $\frac{1}{25}$ of a second, in the middle zone $\frac{1}{50}$ of a second, and in the outer zone $\frac{1}{10}$ of a second, the alterations of light and dark being equal. On rotating the disc it will be noticed that the grey produced in

the three zones is of the same degree of brilliancy, while a quicker speed of rotation makes no difference in the results.

Many fireworks, notably the pin wheel, depend for their brilliancy and form upon this phenomenon of persistence of vision; they are produced by the rotation of a single point of light. Perhaps the simplest of such experiments is when a live spark on the end of a stick is made to revolve, when it produces a ring of light which burns, and yet it is very evident that at any single moment there must be just a minute spot of light and not a ring at all. In such phenomenon the rapidity of rotation is of importance; the motion may be so slow as not to show the presence of a ring of light at all; there must be a certain degree of rapidity, and from observations made by D'Arcy the average rate of rotation should be one revolution in $\frac{13}{100}$ of a second, but the rapidity varies with different bodies. Thus in some cases it is only necessary to have a revolution of once in $\frac{1}{48}$ of a second. This is the measure of the duration of the impression produced on the retina with almost full intensity, but there is reason for thinking that the duration is often less than this, then it decreases and fades away entirely. Altogether the time of duration may be taken as $\frac{1}{3}$ of a second. The spokes in a revolving wheel are also invisible from the same cause, and the position they occupy takes the form of a nebulous disc.

This persistence of vision gives rise to various colour phenomena of a rather uncertain character, some of which are fairly familiar to many persons. If, for instance, a piece of red paper is hung against a white wall and looked at for a few minutes, and then the eyes cast upwards to another portion of the white wall, a faint green image occupying the place apparently of the red paper is observable. If a piece of yellow paper be substituted the after-image would have a bluish tint. The first impression, that is, of the red and

yellow paper in the above experiments, produced on the retina is called the positive image; while the next image, which is of a fainter character, is the negative image or after-image. Another method of carrying out this experiment would be to take a sheet of grey paper and place it on a piece of green paper, and look at the latter attentively for several seconds; then suddenly remove the green paper, when its place is taken by a rose-red image, which, however, disappears very shortly. If in place of using green paper, red is used, then the image would have a greenish-blue colour. In the same way blue gives rise to a yellow image, violet to greenish-yellow, orange to a blue, the colour of the image being in all cases the complementary to that of the original colour.

We can explain these colour phenomena according to the theory of Young and Helmholtz in the following manner: In the eye there are three sets of nerve fibres, one set sensitive to green light, another sensitive to red, and a third sensitive to violet or blue light; the grey paper has an equal influence on all the three sets of nerves. When we look at the green paper the green nerves become fatigued and rendered inert; on the other hand, the red and the violet nerves are not much affected. When the green paper is taken away then grey light is presented to these fatigued nerves, which only faintly respond, while on the other hand the red and the violet nerves respond considerably, and between them a sensation of a mixture of red and violet, that of a rose-red image, is obtained. A similar effect which the green nerves have on this image is to make it appear fainter.

Again, take the effect which is produced when a piece of green paper placed on a yellow ground is suddenly removed, and we have an orange-coloured image of the green paper produced. This may be accounted for in this way: The green nerves are fatigued while the red and the violet nerves are still fresh; when the green paper is removed, yellow light is

presented to the eye, and yellow being produced by a combination of red and green, it tends to act upon the red and the green nerves equally, but the green nerves are already fatigued, hence they do not readily respond, and so the red nerves overpower the much weaker green nerves, and the union of the red sensation and the yellow sensation on the paper gives rise to the effect of orange; in this particular instance the violet rays are but little affected.

If a small piece of black paper be placed upon a sheet of red paper and the patch of black observed intently for some time, and it be suddenly removed, there will be observed a luminous spot of red, much more intense than the rest of the red ground. In a similar way, if a green ground be substituted for the red the after-image is much more intensely green. We may explain these effects by considering that where the black spot is focussed upon the retina the nerves on that spot are not affected to any degree —at all events the three sets of colour nerves would be equally affected; but the red or green nerves on the other portions of the retina are more or less fatigued, and this fatigue causes a reduction in the intensity of the sensation they produce; while on the other hand, where the black spot has been, the red and green nerves are quite fresh, and readily produce the appearance of a more intense image than the rest of the ground.

This experiment also illustrates another phenomenon which is very frequently met with, and that is, that when a coloured object has been looked at for some time, or when a range of objects of the same general colour, such as reds or greens, have been under observation for a long period, the eye appears to lose its sensitiveness, and then the colours of the objects begin to appear dull, and lose their brilliancy. This may be explained from the fact that the coloured light from any coloured object is not quite pure,

and that therefore, while in the main it acts upon one set of nerves, the other two sets are brought into action to some extent; thus red light excites to a considerable degree the red nerves—it also excites slightly the green nerves and the violet nerves. The red nerves soon begin to be fatigued and lose much of their power, while the other sets of nerves are but slightly affected, and gradually the sensations of green and violet will be added on to the red, and so the colour will begin to get more greyish or of a dull tone. In the same way, while green excites most powerfully the green nerves, yet the red and the violet are slightly affected; the

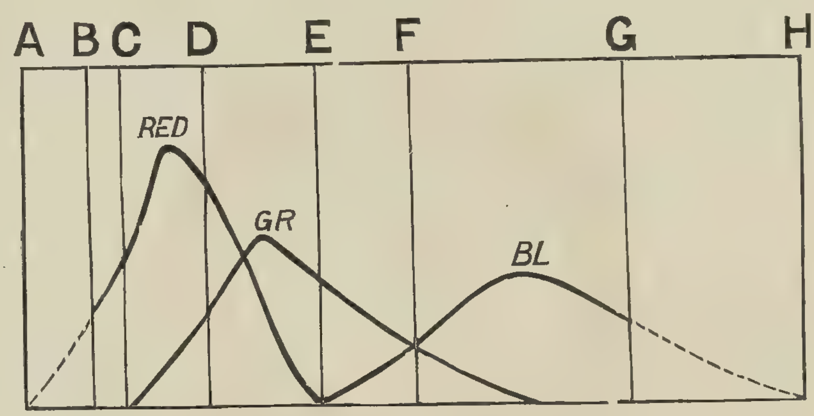


FIG. 58.

green soon loses its power, and the red and the violet begin to exert their influence and a greyish-green is the result.

Clerk Maxwell has investigated the sensitiveness of the colour-nerves of the eye, and has shown that, while the red colour-nerves are most excited by red rays, they are also excited in a much lesser degree by other colours; in the same way the green colour-nerves are most sensitive to green, but are also sensitive to other colours; and similarly the blue colour-nerves are most sensitive to blue, still other colours excite them to a lesser degree. Fig. 58 shows the curves of sensibility which Maxwell has drawn for each of the three sets of colour-nerves.

PLATE VII.

Dyers, calico printers and cloth lookers, who have to examine and pass coloured goods, find their judgment warped when they have been looking over a number of pieces of the same colour, the later pieces not appearing so bright or of the same tone as the earlier pieces. To overcome this defect they have to pass from one range of coloured goods to another range—as, for instance, from reds to greens or blues.

Perhaps this peculiar phenomenon is rendered more intense if in place of the patch of black on a coloured ground we employ a patch of a colour complementary to that of the ground—as, for instance, a patch of green on a red ground,

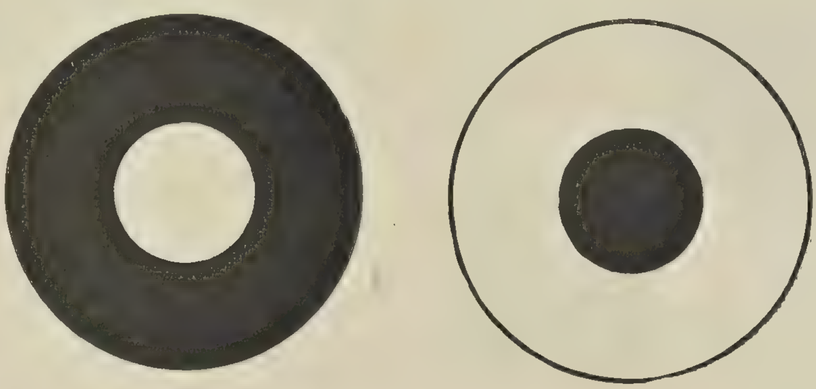


Fig. 59.

or a patch of red on a green ground. When the patches are removed the subsequent after-images are much more intense, because we have fatigued the nerves affected by the green or the red patch, and the green or red after-images have a much stronger action upon the red or the green nerves, as the case may be, and are much more intense. Many examples of such colour phenomenon might be given, but these are sufficient to illustrate what are commonly known as "successive contrast"; when we look upon two different colours in succession to one another. Persons who have, in the course of their business, to examine tints of coloured bodies, find this phenomenon of successive contrast to have a material

influence upon the degree of perception of colour shades and tints.

The eye is not a perfect optical instrument; thus it is subject to the phenomenon known as irradiation, and also to errors from imperfect judgment as to size, direction and relative distances or direction of objects; thus in Fig. 59 we have a black spot on a white ground, and a white spot on a black ground—the two spots are identical in size, but according to the eye the white spot appears to be larger than the black spot. In Fig. 60 we have another example of this, where a square is divided into four equal squares, two

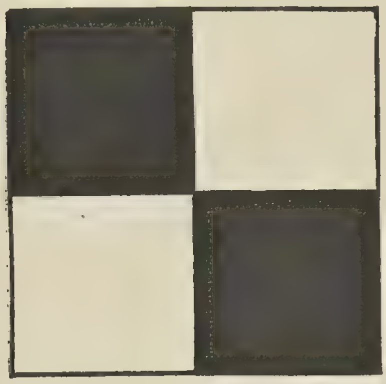


Fig. 60.

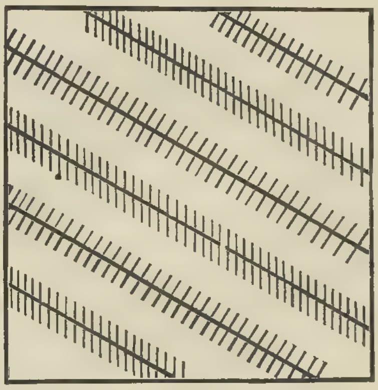


Fig. 61.

white and two black; on looking at these from a distance the white squares will appear to be larger than the black squares, and further that they are joined together by a strip of white, while, as a matter of fact, they only touch each other at the corners. Fig. 61, which is commonly known as Zollner's lines, illustrates another manner in which the eye is but imperfectly capable of judging correctly. The long diagonal lines do not appear to be parallel, although they are; their slope appears to differ. This is the effect caused by the short lines which cross them—without these crossed lines the long lines would appear to be what they are, parallel. Then the judgment as to the actual length of a line is much

influenced by the relationship of other lines; thus in Fig. 62 the two lines A and B are of the same length, but B appears to be longer than A. Another instance of error of judgment as to size is in observing a row of the letter S or a row of the figure 8 (see Fig. 63). Actually, the bottom halves of these figures are a trifle larger than the top halves, but to

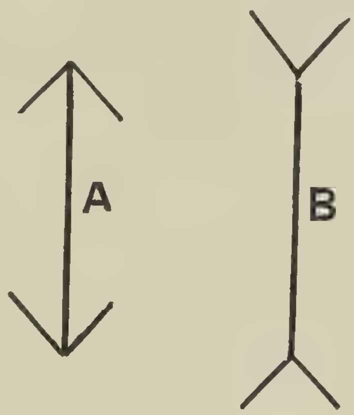


FIG. 62.

the majority of persons the top halves appear to be the same size as the bottom halves.

We have seen above that, by bringing about the fatigue of certain sets of nerves, we can produce an image of an object in a different colour to that it originally represented. These colours are sometimes known as subjective colours, and we can produce them in various ways. For instance,

S S S S S S S S S S

8 8 8 8 8 8 8 8 8 8

FIG. 63.

if a disc of card is painted in alternate black and white sectors, and placed upon the rotating machine and rotated—or black painted upon a white ground—on rotating, the resulting disc will, after a short time, acquire a certain colour according to the speed of rotation; thus a slow rate gives rise to the production of a green hue, while an increase in the rate of revolution changes it to a rose colour. Rood

describes a method of observing these subjective colours by viewing the sky through a revolving disc with sectors; with a slow rate of revolution the sky has a red tint, with a higher rate of revolution a bluish-green tint was obtained in the centre, the outer portion being purple. The passage of a current or shock of electricity through the eye gives rise to the production of subjective colours, which vary with different persons; while persons who have partaken of santonine see white objects in various colours, the violet end of the spectrum being invisible to them.

Colour Blindness.—Many persons are deficient in colour sense. This is independent of the fact that much confusion about colours results from the very defective nomenclature which prevails. The defect referred to is where there is an actual want of perception of certain colours; for instance, a person may be unable to distinguish between a red and a green. This was the case with the eminent chemist John Dalton, to whom red of the most staring hue had the same appearance as a quiet greyish-green. Such persons are said to be colour blind, and the phenomenon itself is known as colour blindness, and very often Daltonism. To such persons the spectrum is usually devoid of variety, they see in it only two or three colours. If they are deficient, as is usually the case, in the perception of the red rays, they only perceive two well-marked divisions, which they call yellow and blue, the yellow including all the spectrum lying between the extreme red and yellowish-green, while the blue includes the rest of the spectrum. Often there is in the middle portion of the spectrum a neutral zone in which no colour is perceptible; in the majority of cases this neutral zone is the position of neutral green to the normal eye.

Maxwell, who investigated this phenomenon of colour blindness with the aid of his discs, showed that any colour presented to them can be matched with the aid of two colours

along with black and white, which proves that colour blind people perceive only two of the three fundamental colours which are visible to the normal eye. Helmholtz has also investigated this theory of colour blindness, and arrived at the same results as Maxwell. The most common form of colour blindness is that one alluded to above, where the colour sensation for red is deficient. In this case, red objects appear more or less yellow, and it is not possible to distinguish between red and green. A common case is where the eye is deficient to the yellow—to such a person red and violet are easily distinguishable, but green and violet are confused together, as are also blue and red. Yellow has the same effect as, and is indistinguishable from, a bright red; one portion of the spectrum is a neutral zone and appears of a grey tint. Again, still more rarely do we meet with persons who are colour blind to violet.

Of course there are degrees of colour blindness, as in other defects. In some persons the defect only occurs to a limited extent; they may be able to distinguish the red from the green, but only just, the difference is not so marked as in the case of a normal-eyed person, while there are other cases where we get the extreme kind of defect, where the person utterly fails to distinguish between various colours. Persons who are colour blind have, of course, considerable difficulty in matching colours—in fact, it is impossible for them to match correctly the different colours. One method of testing for colour blindness is to place before the suspected person samples of dyed cotton of various hues, and ask him to select those of the same kind; and if he mixes reds with greens and reds with yellows, it is evident that he must be deficient in colour sense. It may be remarked, in passing, that it is not sufficient to ask a person to name the colour of a coloured object, and to judge of the efficiency of his colour vision thereby, for a person may not be actually colour blind, but

may give wrong names to the colours; he must be asked to match one colour by means of another colour.

Persons who are colour blind often confuse a colour that is a mixture of red and violet with a colour mixture of red and green; hence colour blindness and the character of the defect may often be ascertained by placing before the colour blind persons objects coloured with mixtures of red and green; red and violet, and of green and violet, and asking them to form matches by the aid of similar colours. A red colour blind person will match a mixture of green and violet with red, while he would not be able to match a mixture of red and green, for to him this would give the sensation of white or grey. A green colour blind person will match a mixture of red and violet with green, while a green or red also would show more or less white to him. The degree of perception of colour varies also with the same person at different periods of his life. This has often been noticed in the case of artists. The colouring of the great artist J. M. W. Turner varied considerably between his early pictures and his late pictures, and this change is usually ascribed to an alteration in the colour perception faculties of the artist.

A normal-eyed person may actually render himself for a brief space colour blind, by looking intently for some time at a red or green surface, or looking through spectacles made of coloured glass. When he has thus fatigued his eye to one of the fundamental coloured rays, he will find that he is not able to distinguish the colours of objects properly. Another plan which may be followed is to heat some soda in a Bunsen burner, when a yellow light will be obtained, whose luminous qualities are such as to illuminate very well the whole of the objects in a room, but it is impossible to distinguish colours, red or green objects appearing to be quite black. Such facts as are thereby obtained serve to show how much colour adds to the beauty of objects.

CHAPTER V.

CONTRAST.

If we look at two coloured objects which are side by side it may be noticed that the sensation of colour or tone which each produces in our eyes is modified by the adjacent colour. This phenomenon was first developed and expounded by Chevreul, who first described the laws by which it is regulated, and by him it was named contrast.

Contrast generally shows itself simultaneously in the observation of two or more colours side by side or close together. There is another form of contrast of colours, and that is, that when, after looking at one colour, we look at a second colour, in the latter case the sensation is more or less of a subjective character, while in the former case the sensation is of a much more tangible character ; we may therefore distinguish, as Chevreul distinguished, between two kinds of contrast known as :—

(1) Simultaneous contrast.

(2) Successive contrast.

Simultaneous contrast is that form where we see two or more colour effects at the same time, and as the phenomenon observable has a most important bearing on the practical applications of colour, it will be of importance to study the matter in detail. We may get two forms of simultaneous contrast :—

(1) Contrast of tone.

(2) Contrast of colours.

By contrast of tone is meant the effect which is obtained when we look at or observe several tones or shades of the same colour. In Fig. 9, Plate 3, we have a rectangular space divided into six equal divisions, which are filled with six different tones, from light to dark of the same grey colour. The experimenter may imitate this very conveniently by taking a piece of Bristol cardboard, and outlining with a pencil a rectangular space and dividing this into six spaces; then mix a light wash of sepia or Indian ink, and brush it evenly over the whole of the six divisions. This wash the experimenter allows to dry. He then covers up the first of the divisions on the left hand and covers another wash over the remaining five; this second wash is also allowed to dry. The two divisions on the left hand are now covered up and a wash applied to the remaining four divisions, and this process is repeated until finally the last division has received its wash, care being taken that each wash shall be laid on as evenly and uniformly as possible, and it is to facilitate this uniform washing that it is recommended to cover up the left hand divisions as each successive wash is applied. Now it will be observed, on looking at this tinted rectangle, that each division does not appear of a uniform colour, but each has a fluted or hollow appearance, although really the whole of the surface of each division is perfectly uniform in tint. This shows us that, whatever may be the reason, our eyes do not always see tints and shades exactly as they are; and further, that the appearance of these tints and shades must have a material influence in the formation of a judgment as to the form of the object observed.

We may get some idea of the cause of the fluted appearance represented by the six strips shown in Fig. 9, Plate 3, by making another experiment which is shown in Fig. 1, Plate 4. Here are shown four strips of grey paper placed as shown in the figure; A and A^1 are of a pale tint, B and B^1 of a dark

one. Now if these are looked at for a short time it will be noticed that a portion of A^1 which is next to B^1 appears to be paler in tint than is A, while that portion of B^1 which is next to A^1 has a darker look than B; it is evident, therefore, that if a pale object is placed next to a dark object it appears

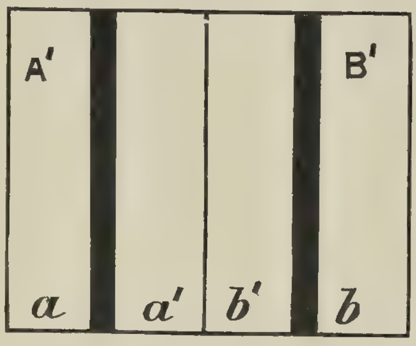


FIG. 64.

to be paler than what it really is, and similarly a dark object next to a light object has a darker appearance than it actually is. If now the middle portions of A^1 and B^1 are covered over as is shown in Fig. 64, leaving two strips of each visible, it will be observed that the adjacent strips a^1 and b^1 have a

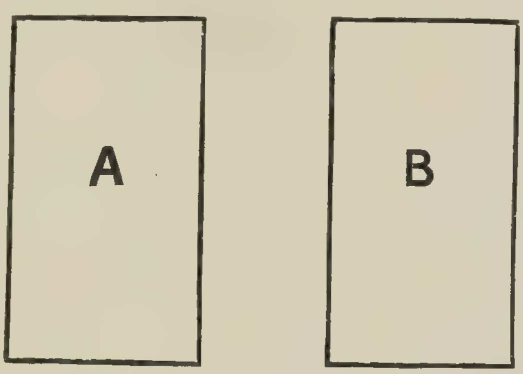


FIG. 65.

stronger contrast of tone than the strips a and b which are removed from one another. This shows us that our judgment is modified by the degree of contiguity of the contrasting objects. If we take the two strips A and B of Fig. 1, Plate 4, and place them at a short distance apart as shown in Fig. 65, it will now be seen that the contrast between A and B of

this last figure is by no means so great as between A^1 and B^1 of Fig. 1, Plate 4.

This contrast of tone is observable with all colours when we look at different tints at the same time. The reader is advised to experiment on this phenomenon by using strips of coloured papers, light and dark shades of the various colours, and placing them in various positions, as indicated in the drawings.

Contrast of Colour.—Contrasts of colour are of a much more complex character than are contrasts of tone, and are modified according to the relative brilliancy of the colours which are contrasted and they are often open to modifications

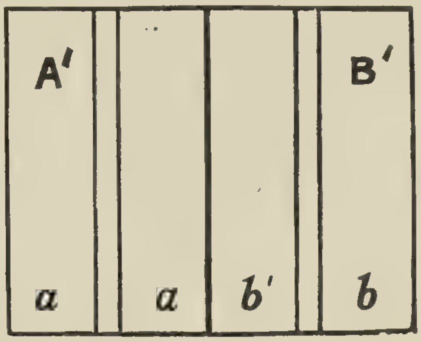


FIG. 66.

of a subjective character, and then they may present contrast of tone, while again, in dealing with contrast of tone, we have to deal with simultaneous contrast. In regard to the contrast of colour we may have also to consider successive contrasts in addition to simultaneous contrasts. If, in carrying out the experiment which is illustrated in Fig. 1, Plate 4, we use two different colours as shown in Fig. 2, Plate 4, we make A and A^1 all red and B and B^1 all yellow, it will be seen that the appearance of A^1 and B^1 to the eye is not the same as A and B. Now it will be observed that A^1 will appear to have a more violet tone than A, and that B will have a greener tint than B^1. It is evident, therefore, that the relative positions of the two coloured spaces A^1 and B^1 have

brought about a modifying influence upon the appearance of the coloured strips as represented to the eye. It may be also shown by arranging the strips A[1] and B[1] as illustrated in Fig. 66, that the contrast or modifying influence of one colour upon the other is greater if they are close together than when they are farther apart. By carrying out a number of experiments with different coloured spaces, which can be conveniently done by means of pieces of coloured papers or dyed cloths, neither of which should have any lustre, the contrasting influence of one colour upon the other may be observed.

The following table shows the influence which one colour bears upon the other when subjected to this simultaneous contrast, taken chiefly from Rood:—

	Colour pairs	Modification by contrast.
No. 1.	Red	Inclines to violet.
	Orange	,, ,, yellow.
,, 2.	Red	,, ,, violet.
	Yellow	,, ,, greenish-yellow.
,, 3.	Red	Becomes more brilliant.
	Green	,, ,, ,,
,, 4.	Red	Inclines to orange.
	Blue	,, ,, green.
,, 5.	Red	,, ,, yellow.
	Cyan blue	,, ,, blue-green.
,, 6.	Red	,, ,, orange.
	Violet	,, ,, blue.
,, 7.	Orange	,, ,, red-orange.
	Yellow	,, ,, greenish-yellow.
,, 8.	Orange	,, ,, red-orange.
	Green	,, ,, bluish-green.
,, 9.	Orange	Becomes more brilliant.
	Cyan blue	,, ,, ,,
,, 10.	Orange	Inclines to yellow.
	Violet	,, ,, bluish.
,, 11.	Yellow	,, ,, bright orange.
	Green	,, ,, blue.
,, 12.	Yellow	,, ,, orange-yellow.
	Cyan blue	,, ,, bright blue.

	Colour pairs	Modification by contrast.
No. 13.	Yellow	Becomes more brilliant.
	Bright blue	,, ,, ,,
,, 14.	Green	Inclines to yellow.
	Blue	,, ,, violet.
,, 15.	Green	,, ,, yellow-green.
	Violet	,, ,, reddish.
,, 16.	Greenish-yellow	Becomes more brilliant.
	Violet	,, ,, ,,
,, 17.	Blue	Inclines to greenish.
	Violet	,, ,, reddish.

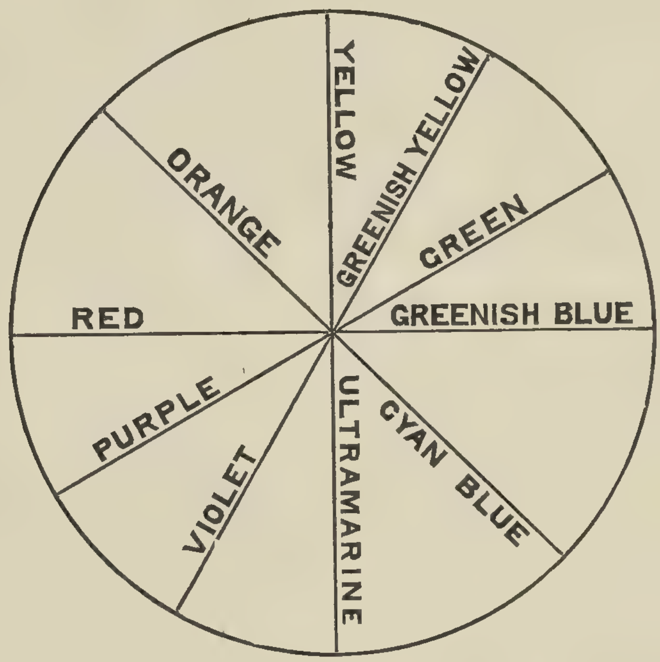


Fig. 67.

If this list of pairs be examined and compared with a chromatic circle given in Fig. 67, particularly noticing the relative distances diametrically of the pairs, it will be observed that the effect of contrast is to throw each member of the pair farther apart. Thus with pairs that are already situated as far apart as they possibly can be, as is the case with complementary colours, the effect of contrast is to render each much more brilliant and distinct.

The effect of contrast may be studied in several ways other than those already mentioned; thus in Fig. 68 it may

be shown by means of a revolving disc. This revolving disc is white with four coloured sectors, which may be green or red or yellow as may be desired. In the middle of the sectors are placed, as shown in the figure, strips of black; on rotating the disc the coloured sectors will produce a coloured ground, while the black strips will produce a ring of grey, but it will be observed that this ring of grey becomes tinted with the colour complementary to that of the ground and contrast effects thereby obtained.

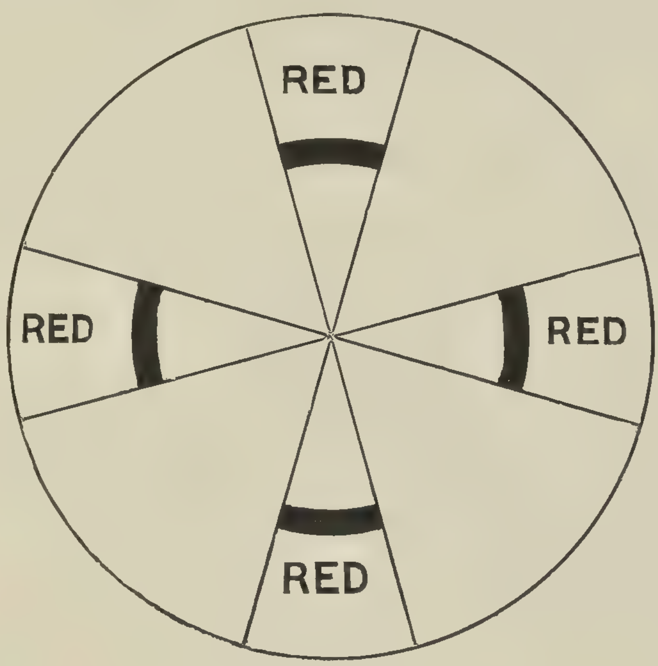


FIG. 68.

Another form of apparatus which can be employed for this purpose is that devised by Ragona Scina, shown in Fig. 69. This consists of two pieces of board placed at right angles to one another, and covered with white cardboard or white paper. From the angle where the two boards meet there projects at an angle of 45° a piece of deeply coloured (preferably ruby) glass. Now if the eye be placed in the position shown in the drawing, it will receive light from two sources: (1) light that is reflected from the bottom of the

apparatus, which passes through the coloured glass, will be coloured; the eye will also receive light reflected from the side of the apparatus, which is reflected from the upper surface of the glass, and will consist mostly of white light. If a piece of black paper is attached to the right side of the apparatus, the reflection of this will be seen by the eye as if it formed a red patch, if the coloured glass be of a ruby tint, and will appear as if it were a red square at the bottom of the apparatus. A small square of black is placed at C; this will prevent any light being reflected through the glass to the eye

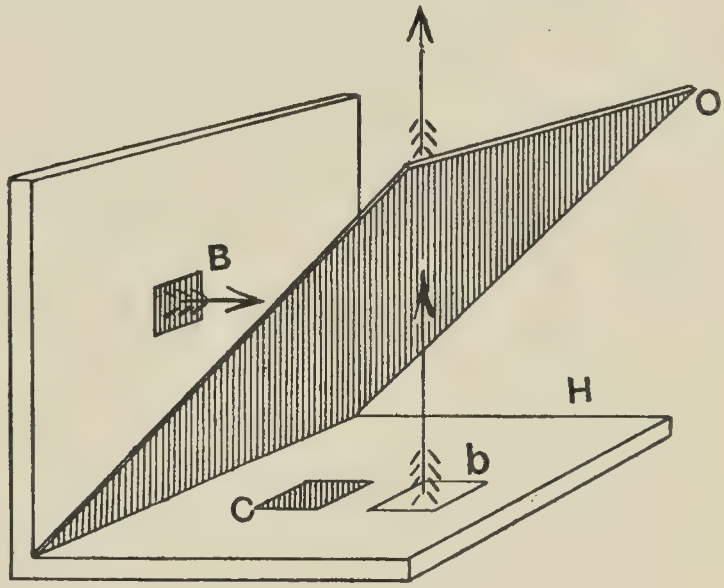


Fig. 69.

from that particular spot, and it should make its appearance as a black patch; but owing to the fact that the upper surface of the glass is reflecting white light, the patch shows itself as a grey; but being beside a red patch we have the effect of contrast, and the grey patch acquires more or less a greenish tint. That this is so may be shown by removing the black square B from the right side, when the patch C will show itself in its true appearance, grey on a pale red ground. If, in place of employing a red glass, a blue glass were used, then the grey patch would assume an orange-grey tint.

A very interesting series of experiments in contrast may be made by producing shadows of an object side by side with various coloured lights, white, etc., and noting the tints of the shadows thus obtained; for instance, if a rod of wood or metal be held in front of a white screen, and it be illuminated by sunlight from an aperture in a window, we shall have produced a grey shadow on a white ground. If now a candle or gaslight be placed near, a second shadow of the rod, close to the first one, will appear; we shall have now the appearance, not of a second grey shadow, as is really the case, but of a blue shadow on a yellow ground. This is brought about in this way, that the sunlight illuminates with pure white light all the surface of the screen except that occupied by the shadow caused by the rod; the candle illuminates the whole of the surface with a yellow light—that is, yellow in comparison with the sunlight—except that portion covered by the second shadow of the rod, and this is illuminated by white light, which, however, by contrast with the yellow of the ground, acquires a decidedly blue tint. To obtain the best results in carrying out this experiment it is desirable to have the shadows as nearly of the same intensity as possible, and this can be done by regulating the amount of sunlight which is admitted. If the shadows be observed through a tube whose inside surface is blackened, then the shadow caused by the candle flame will appear to be blue, and the shadow caused by the white light will appear to be yellow, from the effects of contrast. If now the position of the tube is changed so that only the blue shadow is observed, we get still the effect of blue, although really we are looking at white light, and have no means of producing contrast effects. The candle flame may be even screened off without affecting what is visible through the tube; but if the tube be removed from the eye, the contrast effect immediately vanishes, proving that in this case the effect is due to error of judgment of the eye.

Successive Contrast of Colours.—In dealing with the phenomena of persistence of vision on page 93 we referred to a class of colour phenomena where, after looking intently at a coloured surface, and then transferring the eye to a white surface, there was formed an after-image of the original surface, but in a colour complementary to that originally presented to the eye, and a number of examples were given. The phenomenon here alluded to is of a subjective character, and differs therefore from the objective sensations which are produced on the retina by observation of tangible objects. The image or sensation first produced on the retina is known as the positive image, while the after-image or sensation is known as a negative image. Phenomena such as those already alluded to have a considerable bearing on the impression which colours produce in our eyes, especially when we look at a series of colours in succession; for example, if we have been looking at a red object or a series of red objects for some time, and then turn our attention to blue objects, we find that, so far from the blue presenting its true colours to the eye, it acquires a greenish tint; a white surface viewed in the same way tends to acquire a green tone. Such subjective phenomena are not always readily perceptible, some observers' eyes being more sensitive in this direction than others. A more elaborate illustration is the following. Close one eye, say the right one, and look steadily for a short time at a sheet of red paper—in a few minutes the brilliancy of the sensation will become less; then look at a sheet of violet paper with the same eye—the violet paper will now, however, appear to the eye to be much bluer in tone than it really is. If the right eye be opened and the sheet of violet paper observed, it will appear to be even redder in tone than it originally appeared to the left eye, the contrast, possibly, between the bluish-violet observed by the left eye contrasting with the violet tint observed by the right eye. Such phenomena as

PLATE VIII.

these are explainable by the fatigue of the special sets of colour nerves, which dull the sense of the eye for those particular colours. This has been explained in a previous chapter, to which the reader is referred.

This question of successive contrast of colours, brought about by first looking at one colour and then at another, has a very important bearing on its particular application as to the judgment of the actual colour of coloured objects. It is a well-known fact, among persons who have to examine dyed or printed goods of the same colour, that the eye loses its sensibility, and does not perceive the objects in their true colours; not only so, but if the observer passes through a range of goods of one colour, say red, to a range of goods of another colour, say blue, then the latter is much influenced by the colour effect produced by the former. The following table will give some idea of the modification of colour which is brought about by the successive observation of different colours :—

If the eye has first seen	and then looks at	the latter colour will appear
Red	Orange	Yellow.
Red	Yellow	Greenish-yellow.
Red	Green	Bluish-green.
Red	Blue	Greenish-blue.
Red	Violet	Bluish-green.
Orange	Red	Reddish-violet.
Orange	Yellow	Greenish-yellow.
Orange	Green	Bluish-green.
Orange	Blue	Tinted with violet.
Orange	Violet	Bluish-violet.
Yellow	Red	Reddish-violet.
Yellow	Orange	Reddish-orange.
Yellow	Green	Bluish-green.
Yellow	Blue	Violet-blue.
Yellow	Violet	Bluish-violet.
Green	Red	Tinged with violet.
Green	Orange	Reddish-orange.
Green	Yellow	Orange-yellow.
Green	Blue	Violet-blue.
Green	Violet	Reddish-violet.
Blue	Red	Orange-red.

If the eye has first seen	and then looks at	the latter colour will appear
Blue	Orange	Yellower.
Blue	Yellow	Orange-yellow.
Blue	Green	Yellowish-green.
Blue	Violet	Reddish-violet.
Violet	Red	Orange-red.
Violet	Yellow	Slightly greenish.
Violet	Orange	Yellowish-orange.
Violet	Green	Yellowish-green.
Violet	Blue	Greenish-blue.

Some pairs of colours produced by successive contrast are much more distinguishable and consistent in their appearance than others; for instance, when the eye has looked at red and then at green, the change is brought about immediately. Again, if after having looked at violet we transfer the eyes to yellow, the contrast effect is persistent and readily perceptible; while the contrast effect of blue and orange is intermediate between these two pairs. It should also be pointed out that the depth or tone of the contrasting colours has a very material influence upon the effect which is produced. If the eye has first looked at a reddish-orange and then proceeds to view dark blue, the latter may exhibit a greenish effect; while, on the other hand, normal blue following on normal orange would become more violet.

There is one particular effect of contrast to which attention may be usefully directed at this point. When we have a broad mass of two colours placed side by side as shown in Fig. 3, Plate 4, we get the effect of contrast on both those colours comprised within the rules laid down. When, however, the mass of colour is in the form of fine lines or dots, placed side by side, such as is shown in Fig. 4, Plate 4, and viewed from a little distance, the eye fails to distinguish between each separate line or point, and the effect of contrast is greatly heightened; and in place of seeing the lines or points, one has the effect of a mass of colour, supplementary to those of the colours employed. Thus when the colours

are red and blue the effect produced is violet ; when they are blue and yellow, green is the resultant. This property of colours to mingle is taken advantage of in decorative work by printing or producing, side by side, fine lines or dots of colour, or by overprinting the lines of one colour with those of another, to produce colour effects which could not be conveniently obtained by the direct admixture of the pigment bodies themselves.

This property of the contrast is taken advantage of very largely by designers of figured textile fabrics, who, by a judicious arrangement of the warp and weft threads, can, by using three different coloured threads, produce a design in six tints. For example, by using red, white and blue threads in both warp and weft a figured design in dark red, pink, dark blue, light blue, violet and white, may be produced, the dark red being formed by the crossing of red warp and weft threads, the pink by the crossing of red and white threads, the dark blue by the crossing of blue warp and weft threads, the light blue by the crossing of blue and white threads, the white by the crossing of white threads, and the violet by the crossing of red warp and blue weft threads. Other combinations of colour and effect may be produced, and are largely so, by using other coloured yarns.

Colour Contrast in Decorative Design.—Colour contrasts have a most important bearing upon decorative design in whatever way the contrast effects may be brought about—in the production of wall papers and wall hangings, in calico printing, in weaving coloured figure cloths, the designing of carpets and floor cloths, in painting, and wherever there are brought in juxtaposition several colours which are viewed at the same time. We must therefore devote some considerable amount of attention to the influence or contrast effect produced by one colour upon the other from a practical point of view. Chevreul, who was one of the first to observe the

effects of the simultaneous contrast of colour, was led to do so by having been consulted in a case where merchants refused some printed calicoes on the ground that the colours were not equal to pattern and deficient in depth, pointing out that the blacks were of various tints in the different fabrics. The printers said this could not be, inasmuch as all the patterns were printed with the same black and therefore should have been identical; and while some of the designs were approved of others were rejected, but they averred the colours in these were identical with those which were accepted. By cutting out and comparing independently of the designs of the goods, Chevreul showed that they were identical and of the required degree of strength, and that the effect of the difference in colouring was due to the influence of one colour upon the other when placed together in the design: the black when placed against the red showed a greenish hue, while placed against a green it acquired a reddish tint; moreover, a black placed against a bright colour looked somewhat impoverished.

In Plate 5 is shown an illustration of the effect of various grounds upon different colours. There are four grounds—white, black, yellowish-grey and bluish-grey; taking the various colours we see that the red on white ground appears brilliant and deep, while the ground itself has a tendency to acquire a greenish tint; orange looks bright and brilliant in tone, yellow becomes darker, is less luminous, and is not prominent, and, if anything, shows a tendency to acquire a greenish tint; deep yellow on white is much more satisfactory than pale yellow on white. The contrast between orange and white is greater than that between yellow and white, and is much more effective. Green on a white ground appears to become more intense and of a deeper tone, white evidently improving its appearance. Blue on a white ground shows a better and deeper appearance, the effect being more striking

with deep blues than with pale blues. Violet on white shows a decided contrast, and is enriched considerably. It will be observed that the general effect of a white ground is to deepen and enrich the colours.

A black ground being very much deeper in tone than any other colour, when employed as a groundwork its presence must tend to lower the tone of the contiguous colour, while at the same time its own tone becomes modified. Now, as all black surfaces reflect a little white light, the black becomes tinted with the complementary of any colour with which it may be contiguous. There is one important fact, and that is, that if the contiguous colour be deep in tone, blue or violet and some shades of deep red, the black tends to appear slightly weaker. Red on black has a tendency to become more luminous, and to acquire an orange tone, the black having a greenish tint. Orange and black become much more luminous and of a yellower tone, the black appearing to be of a bluer shade. Yellow on black is one of the most contrasting changes that can be produced; the yellow becomes lighter and much more luminous, while the black has an enriched appearance, due to its acquiring a bluish-violet hue. Green on black becomes more brilliant, but rather lighter in tone; on the other hand, the black acquires a rusty hue and appears impoverished, owing to its becoming tinged with the complementary colour red. Blue on black is a rather poor combination, especially when the blue is of a deep tone, the black becoming slightly rusty in tone; a light shade of blue becomes a little more luminous on a black ground. Violet on black becomes slightly deeper and richer in tone, but, on the other hand, the black loses some of its intensity and acquires a rusty hue.

Colours on grey will vary considerably according to the tone of the ground, for the name grey is a vague one, and is applied to various tints and shades markedly different in

character; thus, in Plate 6, there are given two shades of grey —a yellowish-grey and a bluish-grey—and it will be observed that the effect of these two kinds of grey grounds on the various colours is different. Taking the yellowish-grey we note the following, that red becomes somewhat more intense and deeper, and acquires a bluish hue; orange becomes redder in tone; yellow becomes darker and rather less luminous, much depending upon the relative intensities of the yellow and the grey, pale grey having a tendency to reduce the luminosity of the yellow, while the deep grey increases it; green becomes somewhat deeper and bluer in tone; blue becomes much brighter in tone and is enhanced in quality, while violet becomes somewhat bluer in tone and brighter in appearance. With the bluish-grey somewhat different results will be obtained. The red becomes brighter and somewhat yellower in tone; orange is made a little more luminous and forms a very good combination; yellow is rendered more luminous and deeper; green is rendered lighter and somewhat yellower in tone; violet is somewhat deadened in appearance; while there is little effect on the blue, which, if anything, is rendered slightly less luminous. These experiments will suffice to show that contrast has a very material influence on colours when they are employed in a decorative design. In another chapter some further consideration will be given to the subject of colour from a decorative point of view.

Theories of Contrast.—At the present time there are two theories which have been put forward to explain the phenomena of colour contrast—the psychological theory of Helmholtz and the physiological theory of Hering.

The psychological theory of Helmholtz supposes the existence in the eye of three sets of colour-nerves corresponding to the three primary colours; these have been alluded to in the last chapter. Now a colour not only excites that set of nerves which are peculiar to it, if it be a primary colour, or if it be a

secondary colour the nerves corresponding to the primaries of which it is composed, but also, although to a lesser degree, the nerves of the colour complementary to it; a red colour will thus not only excite the red nerves but the complementary green nerves, the latter only in a minor degree. Both sets of nerves transmit the sensations which have been excited in them to the brain. The latter, however, does not distinguish between the red sensation, which is the real objective colour sensation, and the green, which is a subjective sensation, but only sees, as it were, one colour, which must naturally be composed of two colour sensations, and will therefore be modified accordingly; thus a red will look somewhat yellower than it really is, for red and green colours give rise to yellow. In the same way green will appear rather more bluish and a blue more greenish than it really is. Yellow will appear brighter, because it brings into play all the colour nerves, and therefore excites a sensation of white light in the brain, and this makes the colour apparently brighter than it would have been. When we see two colours side by side, as in Fig. 2, Plate 4, the three sets of colour nerves are excited in a similar manner, and we do not see either colour as it really appears, but in a modified manner; hence we get what are called contrast effects, which have already been described.

The physiological theory, to which Hering has given his support, supposes the existence in the retina of the eye or in the retina-cerebral substance, of a material which is called "vision stuff" ("Seh-Stoff"), and that by the aid of this material the various colour effects are brought about by chemical changes; for instance, the red changes the vision stuff in one direction, green in another, and so on. These changes are considered to be of two classes, one the assimilative or anabolic, which is induced by black, blue and green colours; while in the second the changes are "dissimilative" or catabolic, and are produced by white, yellow and red colours, and

further, these changes may extend outside the area which is directly influenced by the colour cause. One experiment on which Hering relies as a support for this theory can be made as follows: On a large sheet of paper place side by side a large piece of black and a large piece of white paper, the division between the two patches being vertical. Fixed in the centre and touching the vertical division attach two V-shaped pieces of grey paper with apices touching one another, one of the V's being on the black, the other on the white. Look intently at the two V's for a short time, and then transfer the eye to a uniform white surface, when there will be seen after-images of the black and white papers, and of the two grey V's; the after-image of the black and white papers will soon disappear, while that of the V on the black ground looks darker than that of the V on the white ground. In explanation of this phenomenon, Hering considers that it must be due to a material change brought about by the V's in a portion of the retina-cerebral portion of the eye. This chemical theory seems, however, to require the presence of a substance not hitherto found in the eye, and which must be exceedingly sensitive to light reactions. On the other hand, the psychological theory of Helmholtz does not presume the presence of anything not known to be present in the retina, or assume any changes in the nervous system of the eye which are at all unreasonable.

CHAPTER VI.

COLOUR IN DECORATION AND DESIGN.

COLOUR plays a very important part in the decoration and design of the houses we dwell in, public buildings, the ornaments spread around dwelling rooms, and the materials employed in clothing ourselves.

The simplest colour effect is produced when a single colour only is employed, but such colour effect varies considerably in the impression it makes upon our eyes, or, perhaps, more strictly speaking, upon our sense of colour. This colour sense varies very considerably in different individuals—in some being more highly developed than in others; and we find a colour or combination of colours makes a different impression upon one individual than it does on another, and what may be pleasing to the one is far from harmonious to the other. In this respect the sense of colour resembles the sense of sound: a combination of musical notes which would grate upon the ears of one person, whose sense of musical harmony is strongly developed, would be passed over by one whose sense of music is in but a rudimental condition.

The impression which a colour makes upon the eye depends upon several factors—first its character, whether it be red, orange, yellow, green, blue or violet; whether it is brilliant or luminous, dull or sombre. Different colours of themselves convey different impressions to the mind, yellow, for instance, conveys the impression of luminosity or brightness. Blue, on the other hand, conveys the impression of coldness.

Again, red conveys the impression of warmth: hence it is that artists, if they wish to give a bright tone to their pictures, or when it is desired to impart a brightness or warmness to the decoration of a room, employ reds or yellows; while, on the other hand, blues and violets, conveying as they do an impression of coldness, are always used when such an impression is desired. Then, again, colours convey an impression of distance; thus red and yellow always convey an impression of nearness, while blues and greens convey an impression of distance. This is observable on Plates 6 and 7, which give a number of combinations of colours, and it will be noticed that the yellow and red parts appear to stand out much more prominently than the greens, blues or violets. Artists are also well acquainted with this fact, and always, in painting landscapes, give a blue tone to the distant objects of the picture, while this is brought into contrast by a reddish tint which the nearer objects are made to possess.

When, in any scheme of decoration, two or more colours are employed in producing the effect, then we have the question of contrast entering into the case, and the combinations of colours may have a harmonious or inharmonious effect upon our sense of colour. When we have two colours we have the simplest possible case of colour contrast; when, however, there are more than two colours, the colour effect becomes more complicated, and the difficulties of producing a harmonious colour scheme are increased. On Plate 6 is given a design repeated several times in different combinations of colours, which will illustrate the remarks on the harmony of contrast which are given below. The reader examining this plate is advised to cover up those portions of the plate which he is not examining, so that he simply has in view a particular colour combination that he wishes more particularly to observe, and to avoid any effect of contrast with the other portions of the plate. The following tables contain a number

of pairs of colour combinations, together with the effect produced on our sense of colour harmony. Before giving these tables it may be pointed out that much depends upon the tone and brilliancy of the respective colours; thus, for instance, a combination of a crimson with a yellow is a very inferior combination, but if the red inclines to a purplish tint and the yellow to a greenish, the combination becomes a very fair one.

HARMONY OF TWO COLOUR COMBINATIONS.

Crimson and orange	Bad.
,, ,, yellow	Inferior.
,, ,, green	Strong but harsh.
,, ,, blue	Good.
,, ,, violet	Bad.
,, ,, gold-yellow	Good.
Scarlet and yellow	Bad.
,, ,, green	Inferior.
,, ,, greenish-blue	Good.
,, ,, blue	Good.
,, ,, violet	Bad.
Orange and yellow	Poor.
,, ,, yellow-green	Fair.
,, ,, green	Strong-poor.
,, ,, green-blue	Fair.
,, ,, blue	Good.
,, ,, violet	Strong-good.
Orange-yellow and crimson	Poor.
,, ,, scarlet	Poor.
,, ,, green	Bad.
,, ,, blue-green	Bad.
,, ,, green-blue	Fairly good.
,, ,, blue	Excellent.
,, ,, violet	Good.
Yellow and crimson	Poor.
,, ,, green	Bad.
,, ,, blue-green	Very bad.
,, ,, blue	Only fair.
,, ,, violet	Very good.
Green and blue	Very poor.
,, ,, violet	Moderate.
,, ,, red	Good.

From a consideration of the above tables the following rules may be laid down: First, that two colours which are

closely related to one another do not form a harmonious pair—as, for instance, red and orange, and blue and green. This may be observed by comparing the two star designs, Nos. 4 and 7 on Plate 6; on the other hand, blue and red, green and violet, and also red and violet go well together, as may be seen on comparing the numbers 1, 2 and 3 on the same plate. Much, of course, depends upon the tone and brilliancy of the colour, as has been pointed out before.

The following table gives some combinations of pigments and colours and their effect, which may be of service to artists and designers:—

Orange and ultramarine	Good and strong.
Lemon-yellow and ultramarine	Moderate.
,, ,, vermilion	Strong and hard.
Emerald-green and violet	,, ,, ,,
,, ,, purple	,, ,, ,,
,, ,, red	,, ,, ,,
,, ,, orange	,, ,, ,,
,, ,, yellow	Bad.
Ultramarine and carmine	Poor.
,, ,, purple	,,
,, ,, violet	,,
Violet and carmine	,,

On looking at designs Nos. 4 and 7, in which colours are used that are related to one another, it will be noticed that they are indistinct, that indistinctness arising from the effect of simultaneous contrast on the two colours tending to blend them one into the other. By interposing between them either black or white, however, the distinctness of the colours is materially increased, as may be observed on comparing Figs. 5 and 8, in which the following colours, blue and green, and emerald-green and dark green, have been used, but are separated by black in one case and white in the other.

There is another feature of colour which enters into the production of a harmonious colour combination, and that is what may be termed the fulness and relative proportion of the two colours which are used; thus, for instance, while a

colour combination of blue and yellow, in which the blue largely predominates so far as the amount of space occupied is concerned, may be harmonious, on the other hand a combination of the same two colours, in which the yellow predominates, may have a displeasing effect—the yellow, on account of its greater luminosity, overpowering the effect of the blue. No very definite rules can be given bearing on this point, so much really depending upon the tone of the particular colours entering into the combination.

Field has endeavoured to lay down proportions between the various colours—as, for instance, he says that 3 parts of yellow are equal to 5 parts of red, or to 8 parts of blue, or that 11 parts of green formed by the combination of 8 parts of blue and 3 of yellow will equal 5 of red, or again that 13 parts of purple formed by the combination of 8 of blue and 5 of red, will balance 3 of yellow. But all such attempts at colour relations are purely arbitrary, and only true of certain particular shades or tints. No definite rules can be given by means of which the designer can with geometrical accuracy proportion the several areas of the different colours that he uses, and he must, in developing his designs, find the proper balance of colour by trial with the pigments he may be using.

When more than two colours are used in any design, the production of a harmonious contrast becomes much more difficult. The combination of crimson, yellow and blue is good; one of purple, yellow and greenish-blue is good; orange, green and violet make a good combination. A combination of green, yellow and crimson is rather harsh; one of red, yellowish-green and violet-blue is good; while one of red, green and blue is rather poor. In colour combinations of this character, often by separating them by white or black, the effect becomes much more pleasing.

Chevreul lays down the following propositions as explaining the harmonious contrast of colours.

1st Proposition.—In the harmony of contrast the complementary assortment is superior to every other.

2nd Proposition.—The primaries red, yellow and blue, associated in pairs, will assort better together as a harmony of contrast than an arrangement formed of one of these primaries and of a binary colour, of which the primary may be regarded as one of the elements of the binary colour in juxtaposition to it.

3rd Proposition.—The assortment of red, yellow or blue with a binary colour which we may regard as containing the former, contrast the better, as the simple colour is essentially more luminous than the binary.

4th Proposition.—When two colours are bad together it is always advantageous to separate them by white.

5th Proposition.—Black never produces a bad effect when it is associated with two luminous colours. It is therefore preferable often to white, especially in an assortment where it separated the colours from each other.

6th Proposition.—Black, in association with sombre colours, such as blue and violet, and with broken tones of luminous colours, produces harmony of analogy, which in many instances may have a good effect.

7th Proposition.—Black does not associate so well with two colours, one of which is luminous, the other sombre, as when it is associated with two luminous colours.

In the first instance the association is much less agreeable in proportion as the luminous colour is more brilliant.

8th Proposition.—If grey never produces exactly a bad effect in its association with two luminous colours, in most cases its assortments are nevertheless dull, and it is inferior to black and white.

9th Proposition.—Grey, in association with sombre colours, such as blue and violet, and with broken tones of luminous colours, produces harmonies of analogy which have

not the vigour of those with black; if the colours do not combine well together, it has the advantage of separating them from each other.

10th Proposition.—When grey is associated with two colours, one of which is luminous, the other sombre, it will perhaps be more advantageous than white, if this produces too strong a contrast of tone; on the other hand, it will be more advantageous than black, if that has the inconvenience of increasing too much the proportion of sombre colours.

11th Proposition.—If, when two colours combine together badly, there is in principle an advantage in separating them by white, black, or grey, it is important to the effect to take in consideration :—

(1) The height of tone of the colours, and

(2) The proportion of sombre to luminous colours, including in the first the broken brown tones of the brilliant scales, and in the luminous colours, the light tones of the blue and violet scales.

It has already been pointed out that the harmony of a combination is much increased by the luminosity and tone of the colours forming the combination. The material on which the colours are formed has also a considerable influence on the result. A combination which is fairly good on such materials as stained glass and silk, which have a lustre of their own, may be very poor on such materials as cotton or wool, or in tempera painting. But on the question of the influence of material in the harmony of colour more will be said in a subsequent section.

In regard to the use of black and white for the purpose of separating colours the following hints may be found useful: With red and yellow, black is preferable to white; with red and blue, white is to be preferred; with blue and yellow a grey is preferable to either black or white; with yellow or orange, black agrees very well. Grey separates blue and

violet better than either black or white; black should be used with orange and green, grey in connection with violet, while white can be used to separate violet and green. As to whether black, white or grey will give the best results in outlining or separating the various colours of a design, much depends upon the balance of tone of the colours used. The following rules will be found to generally cover all cases of colour combination with which the designer has to deal: (1) if the ground of an ornamental design be of a light tint or tone of colour, and the design itself be deep or intense in colour, then it will be found best to outline the design in black or in grey, or in a colour which is deeper than either the ground colour or the design colour; (2) in the case of an ornamental design, where the figure is of a lighter colour, or a less intense colour than the ground, then it will be found best to outline the figures with white or with a light shade of grey; (3) in monochrome work, where the ground and the design are in varying shades of the same colour, similar rules must be observed. If the ground be dark then the outlines should be white or grey; if the ground be light then the outlines should be of a darker shade than the general colour.

The effect of separating colours by outlines is shown in a number of the figures given on Plate 6 and in the design shown on Plate 7, and the effect of using both black and white for the separation of the same colours is shown on both plates.

The harmony of a design or combination formed of such simple colours as red, yellow, blue, green, orange and violet is readily perceptible, but such is not the case with the more complex hues or shades of browns, olives, bronzes, etc. The differences which exist between these shades need a well-trained eye to distinguish them, and to appreciate the harmony of any colour combinations in which they may

Plate IX.

enter. In nature one often meets with such combinations among the trunks and foliage of trees—as, for instance, the greyish-greens of lichens which grow on the trunks of the trees and contrast with the brownish tints of those members. Or we have the dark tints of the trunks and stems in contrast with the green of the leaves. Then, again, in autumn we get the rust tints which prevail among the foliage of the trees, helping to form combinations of hues which have a most harmonious appearance. Language almost fails to describe such effects, while it needs a master artist to depict them with the pencil.

Following on the lines first developed by Chevreul, it is usual to divide harmonies of colour into two classes :

(1) Harmonies of analogy, and

(2) Harmonies of contrast,

each of which can be further divided into sub-groups, as will be seen presently. It is, however, a more or less arbitrary classification, for by the term harmonies of analogy is generally meant the effect produced by the employment of various tones or shades of the same colour, or what might be termed analogous colours ; while by the term harmonies of contrast is meant the effect produced by the combination of different colours, but the two kinds of harmony often pass insensibly one into the other. If the various shades of yellow and green are employed, they may pass so insensibly from one to the other, that we get the harmony of analogy rather than the harmony of contrast.

Chevreul gives the following classification :—

HARMONIES OF ANALOGY.

(1) Harmony of scale, which is produced when several tones of the same colour are present. These tones may be either so graded as to run insensibly one into the other, when we have the effect generally known as shading, or the

difference may be rather more marked; when the interval between two contiguous tones is greater, the effects of harmony of contrast are often observable.

(2) The harmony of tones or hues. This is obtained when two tones or hues of about the same degree of intensity and power, but belonging to different scales or different colours, are combined together. In many such cases the effect is rather displeasing than harmonious.

(3) The harmony of dominant colour. Such an effect as is here illustrated is obtained when a landscape or picture is viewed through a lightly tinted glass, so that while the colours of the object are readily perceptible, yet they are dominated by the tint of the glass, or the material through which they are observed.

HARMONIES OF CONTRAST.

(1) Harmony of contrast of scale is obtained when two tones of the same colour some distance from one another are simultaneously observed.

(2) The harmony of contrast of hues or tones is produced by the simultaneous view of tones of different heights or depths belonging to relative colours or scales.

(3) The harmony of contrast of colours of different kinds, arranged according to the law of contrast which has already been discussed.

This classification of Chevreul's is rather an artificial one, and is somewhat forced in character; a much simpler classification—if such is needed—is in two kinds of colour harmony only. If particular notice is taken of the harmonies which prevail in nature, paintings, and in good ornamental designs, it will be found that the harmony can be produced in two ways: first, by employing tones or hues of the same colour or of colours which are related to one another; and

second, by the use of different colours which harmonise with one another. For shortness we may speak of this as—

(1) Harmony of succession, or seriation of tones or hues.

(2) The harmony of change of colour.

The harmonies of the first kind are often met with in nature in the petals of flowers, and possibly more particularly in the colours of the leaves in the autumn. We may have a succession of hues passing imperceptibly one into the other, as shown in Plate 8. One sees these effects more particularly in large leaves like those of the oak, horse-chestnut, and the elm. Another example of such harmony would be when we have a succession of tones in red, orange and yellow, or of blue and green, passing insensibly from one to the other. Not only do we find such harmonies of succession or seriation in nature, but the artist finds them extremely serviceable for the production of decorative and ornamental designs for all kinds of objects.

That this is so one may readily see by visiting museums such as those at South Kensington, Liverpool or Salford, and inspecting the great collections of pottery ware, textile fabrics, and ornamental work of all kinds which are to be found in those places, and it will be seen that the designers of them have made full use of the kind of harmony which we have here called seriation.

The infinite gradation of shades which are met with in nature, and produce exceedingly charming effects, are due not only to changes in the colour of the object such as we have been already describing, but also to the play of light upon it. Artists have to take into account the peculiar action of light when portraying a large surface. Supposing, for instance, an artist wishes to depict a large sheet of white paper, or a screen of coloured drapery: if he were to paint them of a uniform white, or of a uniform colour, although he would be representing them as they actually are, yet we should say

that he was wrong. This is due to the fact that the white paper or the coloured drapery is not reflected to our eyes, or does not appear to us to be of a perfectly uniform tone; the play of light upon it leads to the production of infinite gradations of light and shade, which modify our sense of observation. The artist takes this into consideration, and accordingly portrays the white paper or the coloured drapery with some gradations of light and shade.

All the best artists are well aware of this important fact, and pay very particular attention to it. John Ruskin, in his *Elements of Drawing*, shows that he is perfectly well aware of the importance of gradation of tone, and gives this advice: "And it does not matter how small the touch of colour may be, though not larger than the smallest pin's head, if one part of it is not darker than the rest, it is a bad touch; for it is not merely because the natural fact is so that your colour should be graduated; the preciousness and pleasantness of colour depends more on this than on any other of its qualities, for graduation is to colours what curvature is to lines, both being felt to be beautiful by the pure instinct of every human mind, and both, considered as types, expressing the law of gradual change and progress in the human soul itself. What the difference is in mere beauty between a graduated colour and an ungraduated colour may be seen easily by laying an even tint of rose colour on paper and putting a rose leaf beside it. The victorious beauty of the rose as compared with other flowers depends wholly upon the delicacy and quantity of its colour-gradations, all other flowers being less rich in graduation, not having so many folds of leaf, or less tender, being patched and veined instead of flushed."

In monochrome work the succession of tones is of importance for the production of a pleasing and effective picture; when a picture in monochrome work is composed simply of

light and dark shades, the effect is extremely harsh and displeasing, and the art and skill of the painter in monochrome work lie in the careful gradation of one shade or tone into another.

There is another phase of the harmony of succession or seriation, and that is when, as in the spectrum, we have a series blended one into the other—as, for instance, we may cite a design in which the colours are in the following order: green, blue, violet, red, orange.

A design where the following colours were used—green, violet and orange—would be somewhat ineffective; but by the introduction of the intermediate colours blue, red and yellow, the design is made much more effective in character. If these series of colours are not sharply defined by means of outlines, they must shade one into the other, as is the case with regard to the spectrum colours. Much of the harmony in such a case depends upon the relation of form, and the definition of that form by means of outlines, as in the case of foliage of various tints, combined with flowers of different colours. This kind of harmony of succession of colours is very much used in artistic work, but in designing considerable care and skill must be exercised, in order to produce a perfectly harmonious result.

The subject of harmonies of change of colour has already been dealt with fully in dealing with the contrasts of colour, and little need be said about it in this place.

Harmonies of change of colour are greatly influenced by the character of the colours themselves, their relative proportions, and the manner or the use of separating lines of black, white or grey to define the form and scope of the colours. These questions have already been referred to, and the influence of separating them discussed.

In Plates 6, 8, 9 and 10 are shown some designs such as are to be seen in textile fabrics, wall papers, etc. They have

been arranged to illustrate the principles of colour as applied to decorative design as laid down in the preceding sections. In Plate 6 we have the same design in a variety of harmonies and effects of one colour on another. In Plate 8 we have a design comprising the colours orange, yellow, yellowish-green, showing the harmony brought about by using a series of colours in succession.

In Plate 9 we have a design in various tints of red, giving a harmony in tones which is rather pleasing. In Plate 10 we have a design using blue, green and violet, the result of which can hardly be considered very harmonious.

ILLUMINATION AND COLOUR.

We have seen in a preceding section, page 65, that the appearance of a colour or colours varies according to the circumstances or conditions under which it is observed. It will be useful here if we devote a little more attention to this aspect of light and colour, and consider the modifying influence which different kinds of illumination have upon colours of objects under observation.

It must be obvious to any one that the kind and degree of luminosity—or, in other words, the quality and intensity of the light which falls upon them—will vary from time to time, and it is a matter of common observation that the appearance and tint of the colours of such objects vary in degree also. We shall see, subsequently, that the nature and character of the surface of the object also have some influence particularly bearing upon the manner in which the object is illuminated.

Objects are observed under at least four kinds of illumination :—

(1) Direct sunlight or diffused daylight.

(2) Artificial light.

(3) Dominant coloured light.

(4) Two lights of varying quality and intensity.

(1) It is a matter of common observation that the light of day varies much in colour, not only during each day, but at different seasons of the year. The cause of this change of colour in the light is that the atmosphere through which the light reaches the earth in its passage from the sun is not perfectly transparent, and is always more or less clouded in character, the degree of cloudiness varying from time to time from that of a clear bright summer's day to that of a foggy winter's day. Now, when light passes through a cloudy medium, it undergoes changes which vary in degree according to the character and extent of the cloudiness. If a mass of water be observed against a black background it will appear perfectly transparent, but introduce into that water a small quantity of milk or finely powdered chalk, then the water will appear of a bluish colour; the milk or the chalk forms a cloudy medium in the water, which medium has the property of reflecting the blue rays of the spectrum to a greater extent than the rays at the red end of the spectrum, and hence the water appears of a bluish hue. It is for the same reason that the sky appears of a blue colour when observed under ordinary conditions; the atmosphere is filled with minute particles, which reflect chiefly the blue rays of the sun's light, and these blue rays make the skies appear blue. The same phenomenon may be observed in all cases where light is reflected from a medium more or less cloudy, placed against a black background. But the question of the colour of a cloudy medium is a question of degree of the cloudiness: should the cloudiness increase considerably and it is observed more directly, then the reflected rays which are bluish, being thrown off in all directions, while the other rays of the spectrum are transmitted in greater extent, the blue rays tend to lose their transparency, and therefore the light which is transmitted

through a cloudy medium tends to acquire an orange tone. It is for this reason that sunlight, when observed through a foggy atmosphere, is of a red colour ; and for the same reason the sunset hues appear of a red character, because they are transmitted through a greater thickness of atmosphere than is the case when the sun is more directly overhead, as it is at noonday. Street lamps, for the same reason, have an orange colour on a foggy day, the particles of aqueous vapour, etc., which constitute the fog, having a sifting action upon the light from the lamps—the blue rays are reflected and scattered in all directions, while the orange and yellow rays are transmitted.

There is another feature of a cloudy medium which must also be noticed : if a ray of light be sent through clear water, it will pass through practically unchanged, and the water is not greatly illuminated as a whole; but place a small quantity of milk in the water, and immediately the whole tankful becomes more or less illuminated with a diffused light of a bluish character if observed by reflected light, or of a yellowish or orange tone if observed by transmitted light. This is due to a scattering of the light caused by repeated reflections from one particle to another of the substances which cause the cloudiness of the water, and it is at once obvious that this scattering of light, by reason of its large surface, must lead to a reduction in the intensity of the light that passes through a cloudy medium. This is the reason that lamp lights and sunlight lose so much of their intensity during time of fog.

It is necessary to point out that a great deal depends upon the size of the particles of the cloudy medium, as to the degree of their action upon the light which falls upon it, or is transmitted through it. If small, then they have the effect described above; if large, they have very little effect whatever. And thus it is that under certain conditions of fog

and mist, the only effect is to reduce the intensity of the sunlight, but not to alter the quality of its colour; and thus also it is that sometimes the light reflected from the clouds appears to be white, while at others it appears to have a greenish hue, due to variations in the size of the particles of aqueous vapour composing the clouds.

(2) Illuminations by artificial light. Artificial lights—gas in its various forms, oil, and the electric light—play at the present time so large a part in the illumination of rooms, that it is important to consider their effect upon the colour of objects, etc. It has been shown in a previous section what effect the light of one colour has when it falls upon other colours. Now, in the case of most of the artificial lights, the light emitted from them is not a pure white light, but is usually more or less tinted, the prevailing tint being yellow in the ordinary flame of gas, oil and the incandescent electric light; and therefore the changes which have been brought about are those which have been shown to occur when yellow light falls upon any colours. It is a well-known fact that there are many colours which perceptibly change their hue when exposed to artificial light. Some of the blue and green dyes which the textile colourist uses have this effect—the green tends to become rather bluish in tone, so that it is often impossible to see by night whether a particular shade of dyed cloth is actually green or blue. Blacks which by daylight are bluish in tone, show a dead black under gas-light. Blues tend to become greenish, and hence in designing, where the object is to be shown under artificial light, it is necessary to substitute green for blue, or to employ a blue of a reddish hue rather than a blue of a greenish tint. The pigment smalts changes colour in a similar manner. The amethyst, which is a pale blue by day, is a dark red at night. The sapphire, which is blue by day, exhibits a violet tint by night. Some flowers of a blue colour show a reddish

tint by gaslight. All these effects are due to the deficiency of the ordinary artificial light in the blue and violet rays, and therefore the objects illuminated appear to be richer in red and yellow than they actually are. In many cases, to make a colour appear to be perfectly white, or to counteract a slight yellow tint that it may have, it is given a bluish tint. This is more particularly shown in the bleaching of textile fabrics, where the bleached fabric has a perceptibly yellow tint. To avoid this effect it is customary to pass the fabric through a liquor containing a small quantity of blue dye-stuff; the slight amount of bluing that is thereby given destroys the yellow effect, and the fabric appears white in daylight. In gaslight, however, its effect is not seen, and the fabric loses its brilliant appearance and becomes more or less dull looking.

The third condition under which the illumination of objects takes place is that when seen under a dominant coloured light, which has a very material effect upon objects seen under its illumination. A reference may be made to a previous section, in which the effect of one coloured light falling upon another has been discussed in some detail. One may conveniently observe these effects by looking at a landscape, for instance, through pieces of coloured glass; if, for example, a piece of yellow glass be used it will be noticed that, while all yellow portions are intensified but are otherwise unchanged, the red objects tend to acquire an orange cast. Blue objects become a greyish-green colour, and green objects of a yellowish-green colour, and so on, in many cases the effects obtained are more or less considerable; and, by viewing landscapes through variously tinted glasses, one may often produce the changes in appearance due to various seasons. It may be pointed out, however, that the effects observed by viewing objects through a coloured glass are not the same as when viewed under a coloured artificial light, because all

objects illuminated by daylight reflect more or less white light, and this white light modifies the effect as seen through the coloured glass. On the other hand, when an object is illuminated by a dominant coloured light—such as, for instance, that which is obtained from gas or electric light enclosed in a coloured globe—the changes are very different; but as we have already given details relating to this matter, it need not be discussed further.

We come now to the fourth case—that is, illumination by two lights of different quality and intensity. This double illumination produces striking effects, and is met with very frequently in nature, especially at night in such places as blacksmiths' forges, street illumination, and in the case of conflagrations. It is very difficult to lay down any laws governing the case of double illumination, so much will depend upon the kind and relative degree of the two sources of light. A very simple experiment may be carried out in the following manner:—

Place a screen formed of a sheet of white paper or white cloth in such a position that it will be illuminated by daylight and by candle light at the same time, and then place in position a rod so that the shadow is thrown by both lights on to the paper. It will now be observed that the shadow thrown by the daylight will be tinged yellow, while that thrown by the candle will be tinged blue; this effect is, of course, produced by the different quality of the two sources of light. The candle light is deficient in blue rays, while the sunlight has a large proportion of such rays. Now the shadow thrown by the candle is illuminated by the sunlight, and in consequence appears to possess bluish rays, because all the surrounding parts of the screen are illuminated by both sources of light, and therefore have a superabundance of yellow rays, and by contrast we have a blue effect of the shadow; on the other hand, the shadow caused by the day-

light is illuminated by the yellow rays of the candle light, and in consequence acquires this yellowish tint. Very curious effects of this character are often to be observed in churches or chapels having stained glass windows. In such places objects are often illuminated and shadows cast by two sources of illumination—the white light from some windows, the coloured light from others; one gets then some very complicated effects. In hilly districts, in time of sunset and sunrise, especially in the former case, one often gets some very peculiar effects of double illumination, inasmuch as the ground and the objects, especially of distant hills behind which the sun is either setting or rising, are often illuminated by the sun's rays, and by the illumination from the blue sky, and this double illumination brings about some curious effects upon the surrounding objects which are more readily observed than described. Artists, particularly, are more apt to observe the contrast effects produced by double illumination, and so they often produce some very beautiful pictures by copying them as closely as possible.

All objects visible to the eye are so because of the light which they reflect, as has been stated in previous sections of this book. And when these objects have been coloured, the cause of their colour has been pointed out; but, in addition to the reflecting action of the different bodies on light, the structure of the surfaces has to be taken into consideration, inasmuch as it very materially affects the intensity or beauty of any colour that the object may have. This may be noticed in the different appearance that the same dye-stuff has when dyed in different textile fabrics; thus on silk a colour is much more brilliant than it is on wool or on cotton. Again, the structure of a textile fabric has a very material influence upon the appearance of a colour. A colour is much richer when it is dyed upon a piece of silk velvet than when it is dyed upon a piece of plain silk; hence it is evident that texture of

surface brings about considerable modification in the appearance of the colour of such surface, and we have now to consider some of the causes which bring this about.

All objects, whether coloured or otherwise, reflect more or less white light—even the most intense black surfaces may reflect from 3 to 4 per cent. of white light. Now, most of this white light which is reflected has considerable influence upon any colour the object may have; generally its effect is to lessen its intensity. One perhaps may notice this point more particularly with metals than with other objects. Metals have considerable power, when they are bright and untarnished, of reflecting light—the greater the amount of light they reflect, the less colour do they appear to have. Owing to tarnishing or other causes the reflecting power becomes diminished, then the metals have a stronger colour. Again, a great deal depends upon the manner in which light is reflected from metallic surfaces, and also upon the angle at which the metal is viewed. If it is viewed in such a manner that the light which is reflected skims the surface of the metal—as when we look along a highly polished plate of gold or silver—the metal may appear to be white; but if we look at it at an angle of incidence, then the colour of the metal begins to show itself; while, if a couple of plates of metal be placed parallel to one another, then the light which is reflected from surface to surface becomes more highly saturated, and we get a strong development of the colour of the metal—gold, for instance, under such conditions acquires a very deep orange colour. It is owing to these repeated reflections that chased or granulated gold has a much richer colour than burnished gold; and in the case of metallic vessels which have highly polished interiors, these appear of a much greater brilliancy than the exteriors, on account of the light which passes in and out of the vessels suffering repeated reflections from the sides. It may be pointed out that the

quality of the light is altered by this repeated reflection; it becomes saturated with colour, while there is a less amount of light reflected from the surface of the metals in this way.

The influence of surface structure is also seen, particularly in painting, in the differences which exist in the appearance of the same pigments when used in water-colour drawing, or in fresco painting, or in oil-painting: in oil-paintings the surface being more transparent and homogeneous, the colours have a more intense and brilliant appearance; while in water-colour paintings the surface is more opaque, and the colours are by no means so intense. To a large extent the greater amount of white light which is reflected from a water-colour drawing than from an oil-painting helps to bring about this reduction in the intensity of the colours.

A similar state of things exists in regard to pottery and porcelain: colours have a brilliancy and intensity on glazed porcelain which they do not possess on unglazed porcelain, due to the greater amount of light which is reflected directly to the eye, and to the fact that the light penetrates more into the body of the porcelain, and therefore gets better saturated than it does in unglazed porcelain, before being reflected to the eye.

Colour plays a very important part in the decoration of textile fabrics; it is, however, materially influenced by the character of the fibre on which it is applied. The colour of textile fibres is produced partly by reflection and partly by absorption. When light falls upon the coloured fabric a small portion is reflected as white light, a somewhat larger portion as coloured light, while some passes into the fibre, and then the colouring matter on the latter exerts an absorptive effect on the light that passes through it, and causes it to become coloured: it is this portion of the light that ultimately makes most impression on the eye. When one is looking at a single piece of coloured yarn, or a very thin

piece of cloth, the intensity of the colour appears slight, it looks poor and weak; if, however, there are a number of threads or a number of folds of cloth, then the colour appears more intense and strong.

The various textile fibres differ from one another as regards lustre, which depends upon their structure and power of reflecting light. Lustre has a material and beneficial influence on the appearance of dyed fabrics—a fact well known to dyers, who endeavour to enhance the beauty of the colours they produce by imparting a lustre to their goods.

Silk is the most lustrous of textile fibres; wool ranks next, followed by China grass, cotton, linen, jute and hemp, in the order given. Silk owes its lustre to several causes: it is homogeneous in structure, is somewhat transparent, its outer surface is smooth, and thus capable of reflecting light in definite directions; therefore more reflected light reaches the eye from silk than from wool, and the length of the silk fibre, with its smooth structure, allows the fibres to be laid more parallel to one another in throwing and weaving than is the case with any other fibre, and this increases the reflective power of silk fabrics.

Wool comes next in its degree of lustre, but as its surface is rougher than that of silk, it does not reflect so much light, and this is more scattered than is the case with silk.

China grass may take rank next to wool in lustre. Its fibres are long and parallel in formation—a fact which goes a long way to explain its having greater lustre than cotton. The cotton fibre does not possess much lustre. This is due to its short length and its twisted character, which causes it to scatter the light falling upon it and not to reflect it in a definite direction.

Linen, jute and hemp have practically no lustre. They are fibres not homogeneous in structure, and are also some-

what rough, consequently their power of reflecting light is but small.

The effect of lustre upon the colour of dyed fabrics may be observed in dyeing the various fibres with a single dye-stuff and then comparing the results. It will be observed that the colour looks more brilliant on silk than it does on wool, and more brilliant on cotton than on linen or jute. The character of the fabric has also a material influence on the appearance of any colours dyed upon them. Thus a smooth fabric never has so solid an appearance as a fabric with a raised surface. This is strikingly shown by comparing the front and back of a piece of velvet, or a piece of plain black silk, with a black velvet dyed in the same way and from the same materials. The velvet has by far the more solid and rich appearance. This is due to the fact that the pile of velvet, being presented to the light, allows it to penetrate into the fabric and be more completely saturated with colour before being reflected to the eye, while the ends of the fibres forming the nap or pile reflect but little white light, and therefore the light from the substance of the pile is not interfered with. Silk velvet is richer in appearance than cotton velvet, because of the greater direct reflective power of the fibre, cotton scattering the light more.

The loose fibrous structure of the dyed woollen cloth causes it to have a greater appearance of solidity than has dyed cotton cloth, or even worsted cloth, wherein the fibres are kept closer together. Dyed cotton flannelettes, for the same reason, have a better appearance as regards depth of dye than have plain cotton cloths.

PLATE X.

CHAPTER VII.

MEASUREMENT OF COLOUR.

THE practical colourist has very often to test or examine the colouring matters he uses for their actual tone or strength, and a description of the methods in common use for this particular purpose will be useful. It may be premised that we shall not concern ourselves with the methods of testing those properties of colouring matters upon which their application in the various arts of painting, dyeing, etc., depends. The consideration of such properties will be found in books relating to the special subjects, such as the author's *Manual of Painters' Colours* and Knecht and Rawson's *Manual of Dyeing*, to which we refer the reader. What will be described here will be the method for estimating the tone and strength of colouring matters of various kinds.

ABNEY'S COLOUR PATCH PROCESS.

Captain Abney described some years ago a new form of apparatus for the measurement of colour, which he calls a "colour patch apparatus," and which will be found described and illustrated in his book on *Colour Measurement and Mixture*. With this apparatus it appears to be quite possible to measure the desired tone and value of any colouring matter.

The apparatus may be described as follows: The source of the light to be used is an electric arc lamp, which Captain Abney selected because he found that it was a more regular

source of light than any other which he could employ. The light from this arc is allowed to fall upon the collimating lens of a spectroscope, and from thence passes through the prisms of the instrument, and into a photographic camera, on the focussing screen of which it is received as a spectrum. As the reflective powers of the different colours vary considerably, and therefore are not all brought to a focus on the same plane, to allow for this the focussing screen is placed slightly oblique so as to get as equal a focus for all the rays as possible. At a distance of about four feet from the camera is placed a white screen, on which the rays can be received after passing through the camera. When the focussing screen is removed the rays form a confused mass of coloured light ; by interposing a lens this mass of light can be resolved into a patch of white light. If, however, a card containing a vertical slit be put in the place of the focussing screen, there will be obtained a patch of coloured light upon the screen, the colour of which will depend upon the position of the card in the camera, and by moving this card to and fro there will be obtained upon the screen any portion of the spectrum which may be desired. By taking advantage of the fact that the front face of the prism reflects a portion of the light which falls upon it from the collimating lens of the spectroscope, passing this light through a lens of suitable focus, and then reflecting it from a small mirror on to the screen, there can be obtained two patches of white light from the same source, and therefore practically equal in value in every respect. By placing a rod in front of the screen, which can be illuminated both by the light that has passed through the spectroscope and by the light which is reflected from the mirror, we have the means of comparing the two lights in a very correct manner. If their intensities are equal, then the shadows cast by the rod will also be equal in intensity ; if one be stronger than the other, then the shadows will differ also ; by employing

an instrument with a pair of revolving sectors, and placing these in the path of either of the beams of light, the intensity of them may be reduced to any required degree.

The instrument just referred to consists of an electromotor carrying on its spindle a pair of fast and a pair of loose sectors. The latter are so contrived that during their

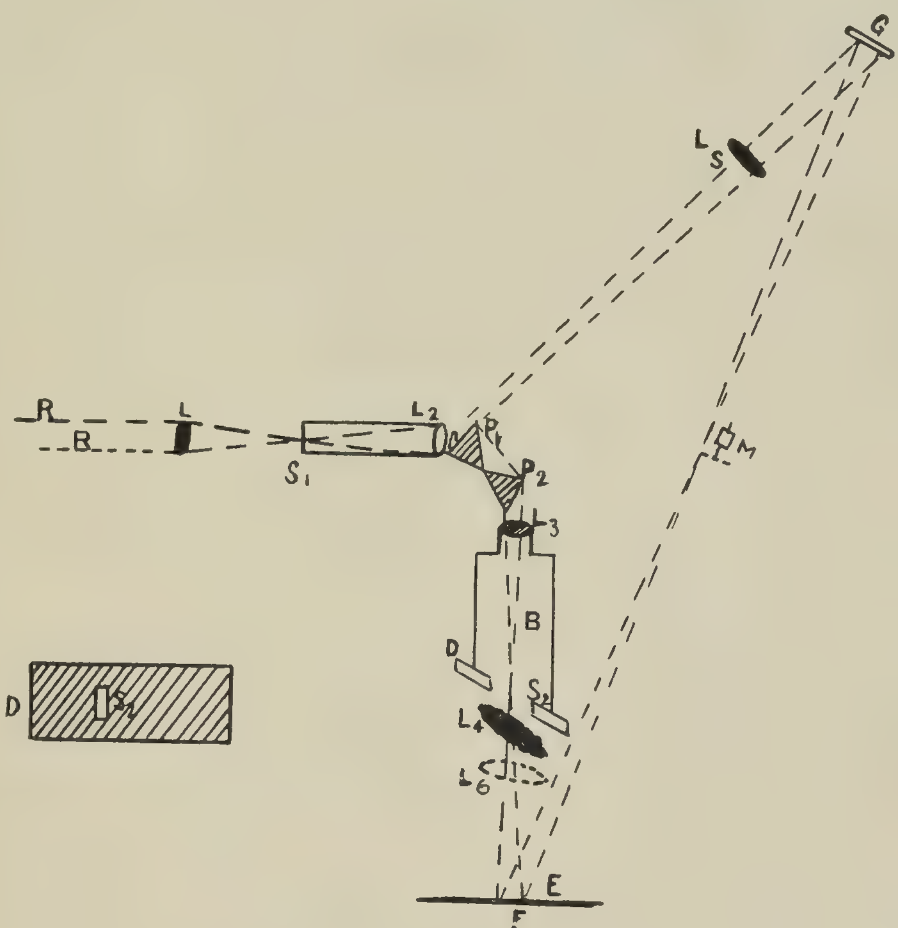


FIG. 70.

rotation the aperture that they form with the fixed sectors can be varied to any required degree, so that the amount of light which is allowed to pass through these apertures may be altered as required. The arrangement of the apparatus is shown in the diagram Fig. 70.

This apparatus can be used for the measurement of colour in this way: The screen is replaced by a revolving disc

arrangement such as shown in Fig. 44; this revolving arrangement carries in the centre a disc painted with the pigment which it is desired to measure; then there are black and white discs so arranged that the proportion of black to white may be altered as required. The apparatus is arranged so that a patch of light from one portion of the spectrum falls upon the screen in such a manner that it illuminates both the centre coloured disc and the black and white sectors; by moving the slit along the spectrum the hue of the central

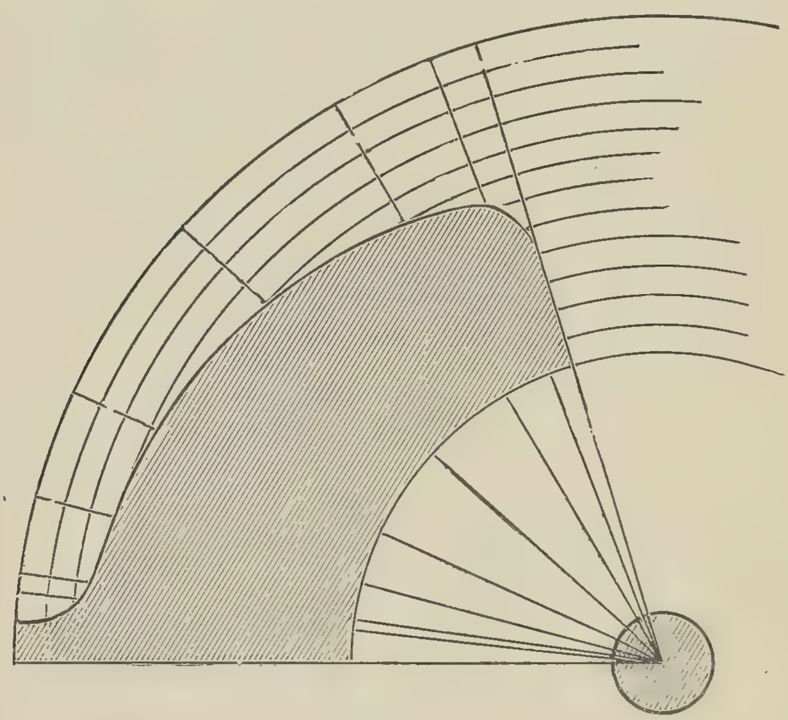


FIG. 71.

disc may be matched, while its luminosity is measured by altering the proportions of the black and white sectors. In this way the exact hue of the colour may be valued, and by passing the slit along the spectrum the amount and character of the rays which are reflected by the pigment can be ascertained by laying down on a diagram the values or the position in the spectrum, or the relative luminosity of the light, and a curve can be drawn as in Figs. 18, 19, *et seq.*; further, it is possible to make a template of a colour which, when

placed in the rotating apparatus and rotated in front of the colour patch of the spectrum produced by the spectroscope on the screen, will reproduce exactly the hue of the colour. This is done by drawing a part of an arc, laying out along one of the radii the relative positions of the various rays of the spectrum, and from these points drawing concentric circles along which the relative luminosities are laid down ; by cutting out the curve so formed, a template is made which, when rotated as described, matches the colour. Such a template is shown in Fig. 71, which is taken from Captain Abney's book.

This method of measurement is only applicable to those cases where the colouring matter is in the form of a pigment, or may be spread upon the surface of a card or other medium.

THE TINTOMETER.

A very convenient apparatus, which may be applied to the measurement of a great variety of coloured bodies, is the instrument invented by Mr. J. W. Lovibond of Salisbury, and named by him the tintometer. The essential feature of this instrument consists of a box, rectangular in section, broad at one end and tapering to the other, in which an eyepiece is placed ; down the centre of the box is a partition dividing the instrument into two parts. If light is permitted to pass along the two tubes which have been thus formed, the arrangement of the parts is such that only one field of view is presented to the eye ; if now there be interposed in one half of the apparatus a coloured body, the field of view of that half will be coloured, while the other half remains white as before. If in the second half of the apparatus another coloured body be inserted, then we have the means of comparing exactly the colours of the two bodies in question ; and if the second coloured body is of a standard

character, we have a means of comparing the first in terms of the second.

There is supplied with the instrument a number of coloured glasses of varying hues and tints and of different intensities, all these glasses being standardised and numbered. These glasses are used in one half of the apparatus, for the purpose of measuring the hue and intensity of coloured bodies placed in the other half of the apparatus, by placing one, two, or more as may be required in slots which are left for the purpose in the body of the instrument. The glasses are selected of such tints as may be best adapted for the particular colour measurements that have to be made.

The tintometer may be used in a variety of ways according to the particular substance whose colour is to be measured. Thus, for example, supposing that pigments are to be examined, then a small quantity of the pigment is placed in a box with a glass lid under one half of the tube, while in another box a quantity of precipitated sulphate of calcium is placed under the second half of the tube, and the light from each reflected through the instrument. On looking through the eyepiece the field of view will be found to be half white and half coloured. The standard glasses are next placed in the white half of the instrument until the tint of the coloured half is exactly matched, and the numbers of the coloured glasses are then noted down for reference. It may be pointed out here that the instrument is first placed in front of a window with a good light. A similar plan may be followed with any other kind of opaque coloured bodies that may be measured by reflected light, such as dyed cloths, yarns, coloured papers, etc.

When the shades of coloured solutions or liquids are to be examined, the instrument is arranged horizontally, and the liquid or solution is placed in a glass trough with glass ends, and the light reflected from a screen through this

trough, the trough being so arranged that it only covers one half of the field of view of the instrument. Then, by placing the standard glasses in the other half, the colour can be measured and a record kept which can be reproduced at any time.

The tintometer can be used to measure the colour of all kinds of coloured substances, and is the most practicable and convenient apparatus for the purpose that has been devised. For a fuller description the reader is referred to

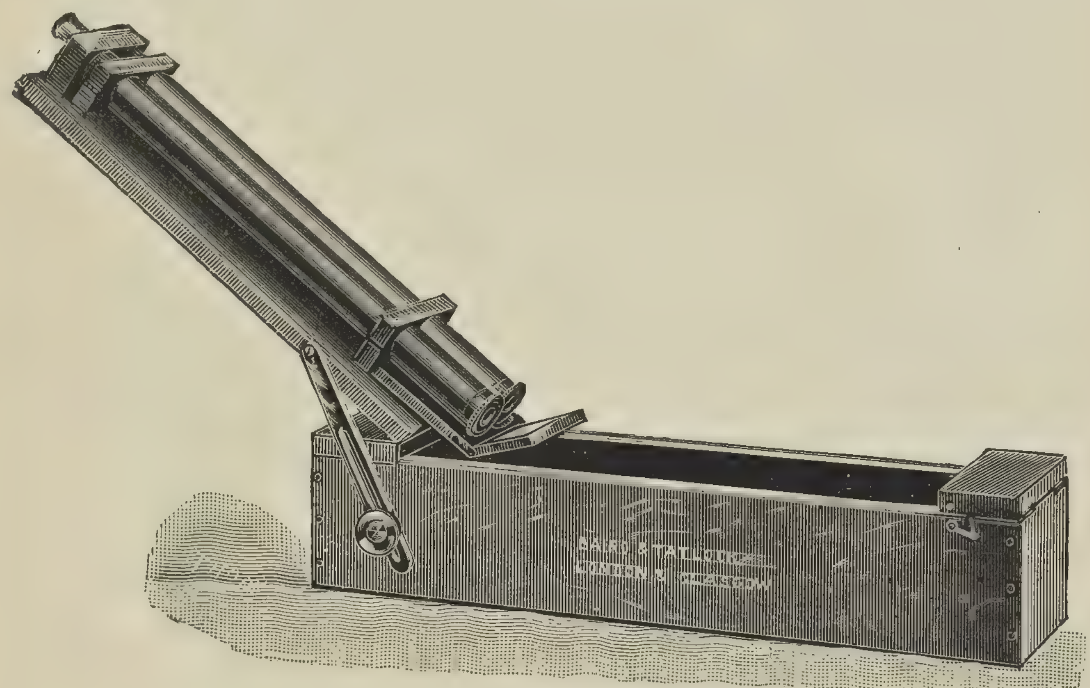


FIG. 72.

Mr. J. W. Lovibond's *Measurement of Light and Colour Sensations*.

For the purpose of measuring tints of coloured bodies various instruments have been invented from time to time. In Fig. 72 is shown the chromometer designed by Mr. Wilson for measuring the colour of petroleum oils, but which may be used for other colourimetric experiments with liquids. This instrument consists of two small tubes closed at each end by a screw cap carrying a stout glass disc: light

is reflected upwards through the tubes by a mirror, and is then, by means of prisms, reflected and brought into an eyepiece; one of the tubes is filled with the oil to be tested, and in the other, which is empty, a disc of tinted glass. On looking through the eyepiece the field of view is seen to be divided by a sharp line formed at the junction of the two images produced by the prisms, one half of the field being tinted with the colour of the oil, the other half with that of the standard. An accurate comparison can then be made of the quality of the oil as regards colour. For the purpose of testing petroleum oil the instrument is supplied with a set of four standard glasses, representing the various grades of the colour of commercial petroleum oil which are recognised.

This instrument may also be employed for measuring the comparative intensities, by filling the two tubes with the oils that are to be compared, and viewing them through the eyepiece.

Many other similar forms of colourimeters have been devised by Ridsdale and others, which, however, do not need detailed description here.

For examination of the comparative strengths of coloured solutions this apparatus may be used in the following manner: A solution of a known quantity of a standard colour in a given quantity of water is made; then a solution of the colour to be tested is also made of the same nominal strength; a measured quantity of the standard solution is placed in one of the tubes, and the same quantity of the other solution in the second tube. An observation is now made by looking down the tubes, as to whether both exhibit the same intensity of colour; if one be lighter than the other, then the quantity of the solution is added to until a new observation shows that both have exactly the same depth of tint. Then the volumes of the two liquids may be taken as measurements of the comparative strength of the two colouring matters.

When a colourimeter is not available, a comparison of two colours, such as two dye-stuffs which are soluble in water, may be made by taking a weighed quantity, say one gramme, dissolving in 100 cc. of water. Next procure two glasses with flat bottoms and of the same diameter and a capacity of about 80 cc.; the diameter need not be more than ¾ inch. Measure into each glass 30 cc. of water and 10 cc. of the dye solution, and then hold the glass in front of a window and compare the colour of the two solutions for depth. To the strongest add water until the tint of the colour in both glasses is identical; then measure the length of each column of liquid, when a measure of the comparative value of the colouring power of the two bodies is obtained.

In the case of pigments the relative colouring power of two samples may be determined in the following manner:—

By comparison with standard sample. Supposing it it a sample of vermilionette whose colouring power is to be determined, then 10 grammes of the sample are weighed ous and mixed with 30 grammes of china clay; the mixing must be thoroughly done. Ten grammes of the standard sample are mixed in the same way with 30 grammes of the same sample of china clay. The two mixtures are now compared together for depth of colour as described above: if the two samples are equal in colouring power, the depth of colour of the two mixtures will be the same; if one is stronger than the other, then one of the mixtures will be darker than the other. Some idea of the relative strength of colouring power can be obtained by adding small and known weights of china clay to the darkest sample, until the tint of all the mixtures is equal; then the samples have a colouring power proportional to the amount of china clay used. Thus, if one sample took 30 grammes of china clay and the other sample 37·5 grammes, then the relative colouring power is as 30 to 37·5; or, if the strongest sample be taken at 100,

then the colouring power may be expressed in percentages thus—37·5 : 30 : : 100 : 80; the weakest colour has only 80 per cent. of the colouring power of the strongest.

Again, in making some experiments to test the comparative colouring powers of Orr's white and white lead, 5 grammes of the former were mixed with 1·46 grammes of blue, and the tint thus formed was found to be exactly matched by a mixture of 5 grammes of white lead with 0·55 gramme of blue. Hence we have :—

$$146 : 55 : : 100 = 236{\cdot}6,$$

that is, 100 parts of Orr's white is equal to 236·6 parts of white lead as regards colouring power.

As the toning colour for all pigments, except whites, a good sample of china clay may be used; gypsum, also, makes a good toning colour; barytes and white lead are a little too heavy. For whites a good animal black makes a good toning colour.

When a large number of assays for colouring power have to be made, a standard tint should be made by taking, say, 50 grammes of the standard sample, and mixing with about twice its weight of the toning colour; this tint may be used in subsequent tests, and will save some time in the preparation of a standard tint. It is important, however, that the same sample of toning colour be used to mix with the samples whose colouring power is being tested, as has been used in making the standard tint.

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